

Volume 1

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PHYSICS AND ENGINEERING LABORATORY

DSIR

NEW ZEALAND



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FINAL REPORT  
LANDSAT II INVESTIGATION PROGRAMME

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No. 28230

VOLUME I

Physics and Engineering Laboratory  
Report No. 587 September 1977

Editors: P J Ellis, I L Thomas, M J McDonnell

Original photography may be purchased from  
EROS Data Center

Sioux Falls, SD

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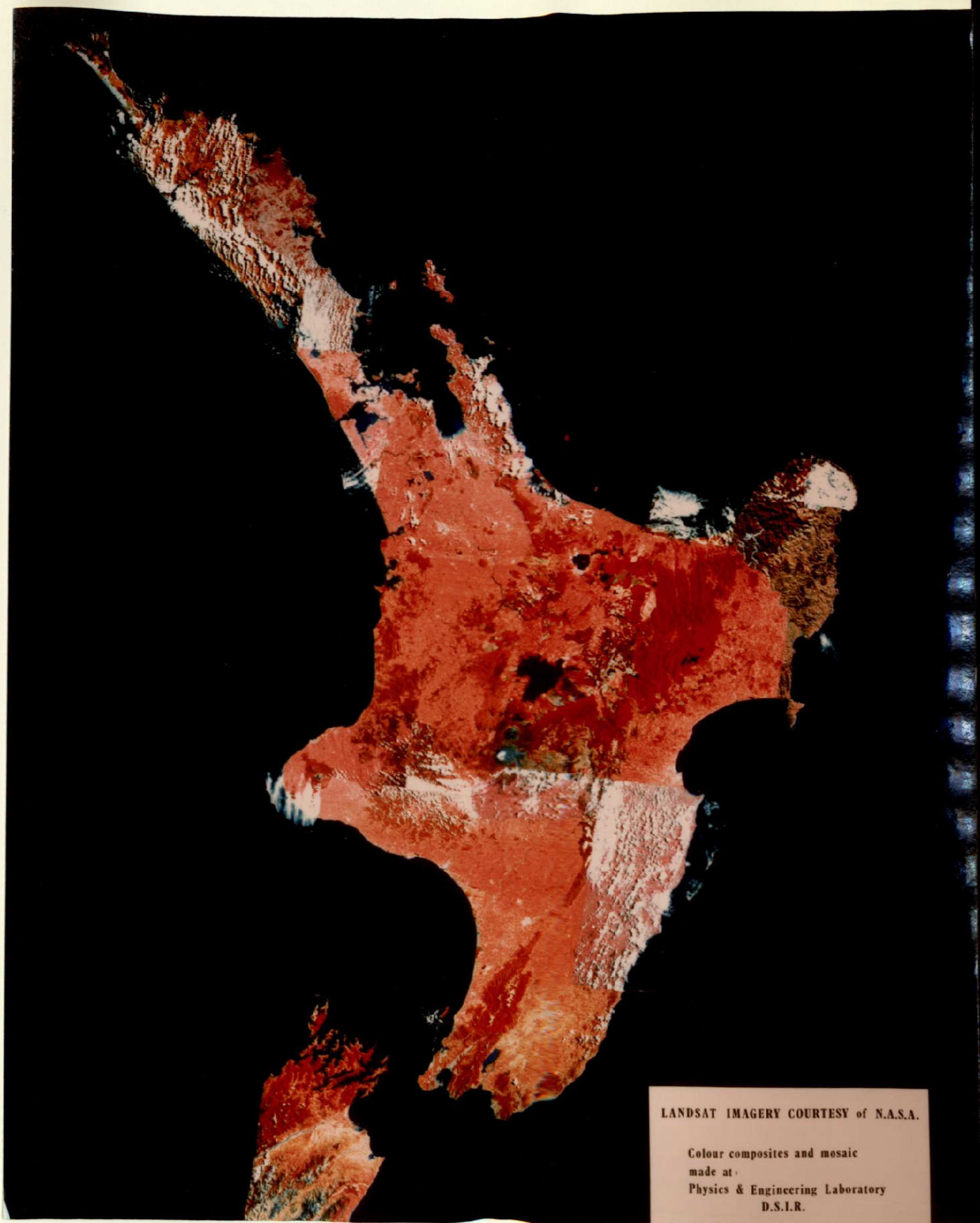
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FRONTISPIECE

These two images are of the North and South Islands of New Zealand. They have been produced at the Physics and Engineering Laboratory by mosaicing together a number of images taken by NASA's LANDSAT I and II satellites over a period of four years. The three image bands used (MSS 4, 5 and 7) have been printed as yellow, magenta and cyan respectively.

## FOREWORD

This is the final report of the Landsat II investigation program which various New Zealand groups have been carrying out under contract to NASA.

A very satisfying feature of the New Zealand program has been the involvement of a number of groups from the Scientific community in this country. Although the formal contract involved only 3 groups (Department of Lands & Survey; the New Zealand Geological Survey, Department of Scientific and Industrial Research; and the Forest Research Institute), working through the Remote Sensing Section of the Physics and Engineering Laboratory, the program has excited the interest of other groups and there are now, at the conclusion of the program, 8 groups actively involved. 14 authors have been involved in the preparation of this report.

In addition to the work on the development of the technology itself, and the exploration of the potential of satellite remote sensing, the imagery from Landsat II has been used in at least two operational programs - in the preparation of a new relief map series for New Zealand, and in the preparation of a new series of aeronautical maps.

The organisation of the project has been such that it has been possible to achieve a high degree of coordination in the New Zealand program. The Remote Sensing Section of the Physics and Engineering Laboratory has been equipped with various aids to interpretation of Landsat images; and it has also carried out research and development on methods of data handling, data reduction, atmospheric measurements, geometric corrections, and photographic processing. In addition the group have carried out specific projects on ship detection, agricultural crop identification, estimation of snow cover, sediment movements, and cartography. In addition, the Remote Sensing Section has provided a service to the three principal investigators and other groups that have latterly become involved in the project. The fact that all groups have been brought together through the joint use of the central facilities has made it easy to co-ordinate the total program; and I would like to pay tribute to the co-operative spirit shown by everybody involved.

To the three principal investigators that were involved in a formal way at the beginning of the program, the following additional groups have been added -

Ministry of Works and Development  
The Geography Department of the University of Auckland  
The New Zealand Forest Service

In this report the authors have attempted to do two things:

1. present in this one document a complete review of the New Zealand program,
2. present each segment of the total program as a paper which is complete in itself.

I would like to take this opportunity of congratulating all of the groups involved on the excellence of the results they have achieved.

It is also appropriate at the conclusion of this formal contract, to offer our sincere thanks to NASA for agreeing to include New Zealand in this program, and to our very many friends on the staff of NASA for the tremendous support and assistance they have given us throughout the program and for the unfailing courtesy they have always shown in answering our many questions. From our point of view this has been a first-class example of international co-operation, and I hope that when our NASA colleagues receive this report they will feel that their support of the New Zealand program has been fully justified.

Although this report concludes the present formal contract, we are very anxious to continue work on this new technology and to extend our facilities and interpretive skills. We hope that it will be possible for us to participate in the Landsat III program and we have already signified our interest in participating in the Seasat program.

Once again I extend my sincere thanks to NASA for the support they have given to New Zealand through this program.

M C Probine  
New Zealand Co-ordinator  
Landsat II Investigation Program

## ACKNOWLEDGEMENTS

A large co-operative investigation program involves many people. Without their active support and encouragement the program could not function. The Editors would like to pay tribute to the groups and individuals listed below and to the others who have helped in many different ways.

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Optics Section: Photometry Section: Computer Research Section: Electronics Division: Instrument Development Section: Typing Section and Photographic Section.

Finally, we wish to acknowledge the continuing help and encouragement from Principal Investigator and Assistant Director General of DSIR, Dr M C Probine, Director of the Physics and Engineering Laboratory, Mr M A Collins, Division Head, Mr G McK Allcock, and Commissioner for the Environment, Mr I L Baumgart.

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## PART I

DEVELOPMENT OF REMOTE SENSING TECHNOLOGY  
IN NEW ZEALAND

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CHAPTER 1

THE LANDSAT II INVESTIGATION PROGRAMME IN NEW ZEALAND

SUMMARY PAPER

P. J. Ellis

ABSTRACT

This paper summarises a two-year investigation in which imagery from the Earth resources satellite, LANDSAT II, has been assessed for its possible applications to monitoring the New Zealand environment.

The paper serves as an introduction to the remainder of this report, in which each succeeding paper covers individual topics which together form the investigation. The possible future for spacecraft remote sensing in this country is also discussed.

## 1.1 INTRODUCTION

This is a chronicle of a two-year investigation into the potential applications of satellite remote sensing in New Zealand. The programme started with the reception of the first LANDSAT II scene of this country in October 1975. Since then, 45 scenes of New Zealand have been received, and processed copies distributed to investigators in many different disciplines.

From the beginning the programme was regarded as an exercise in co-operation, with overall co-ordination in the hands of NASA-appointed Principal Investigator Dr M. C. Probine and the Remote Sensing Section at the Physics and Engineering Laboratory (PEL) DSIR. Each discipline group has been responsible for its own interpretation and assessment of the relevant LANDSAT imagery.

The escalation of interest during the two-year period is evident from the steady increase in "discipline" contributions to the quarterly reports to NASA and to this final report. Starting with three NASA-appointed Co-investigators, in the N.Z. Geological Survey, Department of Lands and Survey, and the Forest Research Institute, the contributions have widened to cover several branches of the N.Z. Forest Service, the Soil and Water Division of the Ministry of Works and Development, and the Geography Department of the University of Auckland. Many other organisations, notably the water catchment authorities, Ministry of Agriculture and Fisheries, the Soil Bureau, and the N.Z. Oceanographic Institute have participated in different ways.

We have decided to present this report as a series of individual papers, preceded by this summary paper which outlines the projects, results, and conclusions of the whole exercise. Each of the individual papers covers one topic, and is as complete as can be achieved at this stage of our development. Some of the papers have already been submitted for publication elsewhere, and most topics have been at least partly covered in our quarterly progress reports. To avoid the need to refer to these "interim" documents some repetition of previously reported work is inevitable. This report is arranged in similar part order to our quarterly reports, each part representing the contribution of a particular organisation. The first-named author in each paper is either the project leader for that topic or the principal author, or both.

The LANDSAT project has had "side effects" which are in many ways as significant as the results themselves. The Remote Sensing Section was set up as a "non-aligned" group to provide the technology to assist the imagery users, and to fulfil the twin roles of co-ordination and promotion of remote sensing in general. This lack of affiliation to any single earth-science discipline has made the co-ordinating task much easier, and has enabled the "total concept" of remote sensing from spacecraft and its future to be kept in view. During these investigations the Department of Lands and Survey and the Ministry of Works and Development have each appointed a full-time remote sensing co-ordinator, and very close collaboration has developed between these people and the PEL group.

For most people in this country this investigation has been the first introduction to Earth resources satellites and their applications. Many lectures and seminars have been given in a diversity of locations, and a series of workshops in various aspects of remote sensing is expected to be held at intervals in the future.

The programme has inevitably caused questions to be asked about the possible future of satellite remote sensing in and around New Zealand, and the way that a small country with limited resources should proceed in this new discipline. In this paper we therefore go beyond the immediate programme and consider the implications of future developments and how they might be utilised in this country.

The problem of "cost-effectiveness" of LANDSAT data has been raised in a number of contexts. So far, we have not been able to conduct meaningful studies that itemise the potential cost-effectiveness of an "operational" LANDSAT system in any one discipline. Some general statements can and have been made in this report, and this paper contains proposals for implementing such studies.

It is intended to publish the final report as part of the "DSIR Information Series"; complete with colour plates. The papers therefore contain more descriptive material to assist the general reader than would normally be included in a NASA report.

The following background information about New Zealand, its land, its people, its industry, and its overseas trade, provides a "framework" within which to view the applicability of satellite remote sensing, now and in the future.

## 1.2 NEW ZEALAND

The two main islands and the smaller outlying islands together amount to an area of 26.9 million hectares, of which less than one quarter lies below the 200 m contour. The coastline is very approximately 9000 km long, and the new 200 mile offshore "Exclusive Economic Zone" when declared will have an area of about 4.2 million sq. km, making it one of the largest coastal zones in the world.

The main islands lie between latitudes 34° and 47° south, and longitudes 166° and 179° east. The average rainfall is high, between 250-4000 mm, with large local variations. Mean annual temperatures vary from 15°C in the north to about 12°C in the south, with a small annual range of about 8-10°C.

The population estimate for the country in 1975 was 3.1 million, of which over 70% lives in the North Island.

The economy depends to a great extent on agriculture, with a gross output in 1975 of NZ\$1,329 M, and a total export value (after processing) of NZ\$1,169 M. Pastoral products make the greatest contribution, with 8.3 million hectares of good pastoral

land and 0.5 million hectares of first-class arable land. The 1975 value of pastoral products was NZ\$1,113 M and for arable products was NZ\$56 M. Cereal production is mostly for the domestic markets; annual supply variations cause shortfalls in some years and excesses in others. A large proportion of the arable crops are grown in the Canterbury Plains in the South Island (see Chapter 10).

The other major export categories are forest products (1975 value NZ\$108 M), fisheries (1975 value NZ\$21 M), minerals, and manufactured and miscellaneous products (1975 value NZ\$249 M).

### 1.3 ORGANISATION OF THE LANDSAT II INVESTIGATIONS

Under the terms of the agreement with NASA, attempts have been made to obtain full coverage of New Zealand with the LANDSAT II Multi-Spectral Scanner (MSS). The inability to achieve this coverage has largely been due to the high probability of cloud cover occurring at the time of overpass, coupled with the limited number of overpasses per annum due to the 18-day LANDSAT cycle.

Scenes with less than 30% cloud cover are processed at the EROS Data Center (USA) into 70 mm and 1:1000,000 scale monochrome transparencies, copies of which are sent via the PEL Remote Sensing Section to each Principal and Co-investigator on a standing order basis. Monochrome and colour composite products are made from these transparencies by the Section and distributed to all investigating groups on request. The Department of Lands and Survey makes monochrome sets of "quick-look" prints of each scene and sends these to "standing order" customers throughout New Zealand. Monochrome prints and enlargements are also available to the general public through the Department's Photo Library.

NASA has made an allocation to each Co-investigator of Computer-Compatible Tapes (CCTs), containing the digital data from which the LANDSAT pictures are made. The Remote Sensing Section is as yet the only group with the capability to process these tapes. They are therefore held at PEL and lineprinter or other data outputs are supplied to investigators as needed. Recently, individual investigators have been able to access the CCTs and produce their own outputs and thematic maps via a terminal to a large national computer network (Chapter 6).

To complement the LANDSAT imagery, a PEL-designed aircraft multispectral camera has been available to users, along with a similar commercially made camera belonging to the Department of Lands and Survey. A LANDSAT type radiometer has also been regularly used during ground truth surveys.

Many discipline groups have made use of the developing interpretative laboratory at PEL which now has a colour additive viewer, electronic "density slicer", photographic scanner and digitiser, and on-line computing facility. Users are encouraged to work at PEL for as long as their project requires.

Quarterly and final reports to NASA are the responsibility of the Remote Sensing Section, which co-ordinates the contributions and organises their production and dispatch.

#### 1.4 LANDSAT MSS IMAGERY - GENERAL COMMENTS

During the last two years we have gained a better understanding of LANDSAT MSS imagery and the way it can be used in our local environment. Certain general conclusions concerning resolution, spectral bands, and timeliness of data can be drawn from these experiences and are presented below.

##### 1.4.1 RESOLUTION

Most land-based targets in New Zealand tend to be physically smaller than their counterparts elsewhere, for instance in Australia or the USA. Moreover, a wide diversity can occur within a small area. The field sizes in an important cropping area such as the Canterbury Plains vary between about 2 and 10 hectares - that is, between 5 and 25 picture resolution elements (pixels) of the LANDSAT I and II Multi-Spectral Scanner. Man-made structures such as roads or bridges can sometimes be detected, but details of urban areas are generally insufficient to give more than a broad idea of their composition.

In this respect it is noticeable that enlightened use of the first generation data (that is, the CCT) can result in an improvement in apparent resolution over the present photographic products, particularly if a sophisticated output device such as a "photowrite" machine or interactive video display is used to examine small areas.

Spectral signature analysis usually requires a target of sufficient size, typically 10 or more pixels, to ensure that the measured target radiance is not affected by "adjacency effects" of nearby objects. Experience with LANDSAT II seems to indicate that an increase in spatial resolution would be of benefit by extending the areas open to analysis by satellite remote sensing. We feel that the proposed improvements in future spacecraft instruments (40 m pixels - RBV; LANDSAT C: 30 m pixels - Thematic Mapper; LANDSAT D) will greatly increase the applications in this country. The corresponding increase in data volume should not be a major problem, since most analyses are concerned with sub-scenes which are smaller than the 185 x 185 km original image.

Applications which require greater resolution include: urban development monitoring, detection and mapping of soil erosion, detection of "local" water pollution, detection of crop diseases which usually start in "nodes" and require to be identified before the whole field is infected, and in cartography to assist in the preparation of larger scale maps than is presently possible from LANDSAT I and II.

##### 1.4.2 SPECTRAL BANDS

The present MSS spectral bands (500-600 nm, 600-700 nm, 700-800 nm, 800-1100 nm) are a compromise to satisfy a diversity of applications. The New Zealand programme has concentrated on the use of these bands in its aircraft underflights and ground truth measurements in order to make the best comparisons between these "multistage" results. We have no experience yet of

narrower or differently sited bands in the same general region of the spectrum. Preparations in hand will permit a "library" of continuous spectra of New Zealand targets to be established using a field spectrometer. This data should help to predict the preferred bands and bandwidths for specific future applications.

The results from LANDSAT II so far confirm the overseas findings that MSS bands 4, 5, and 7 (Chapter 2) appear to be most useful for vegetation analysis and analysis of land features in general. All four bands have been successfully used in estuarine studies where the differential water penetration has helped to establish land/water interfaces and to estimate the movement of suspended sediment.

The geothermal nature of New Zealand makes the addition of the fifth "thermal" band on LANDSAT C of particular interest, and it is hoped that eventually the spatial resolution of this band may approach the resolutions of present and planned shorter wavelength bands. Routine mapping of "hot spots" which may change rapidly in sensitive areas such as Taupo may then become possible.

#### 1.4.3 TIMELINESS

For most users the LANDSAT II programme has been their first introduction to Earth resources satellite data, and the "experimental" nature of this data was always appreciated. Consequently the delays in time between satellite acquisition and reception of scenes in New Zealand has not been a major problem. The fickle nature of New Zealand weather and its unpredictable cloud cover have, however, severely limited the number of scenes obtained and have made the acquisition of simultaneous aircraft and satellite imagery of the same region very difficult.

The lack of repetitive coverage in places such as the test sites in Mid Canterbury at critical times of the year has greatly reduced the conclusions that can be drawn from our agricultural project. This emphasises the need for better access to data if the operational use of Earth resources satellites is to be considered.

In spite of these problems, we feel that the small amount of repetitive coverage achieved points out one important feature of satellite imagery which requires further emphasis in this report. This is the ability to detect and record change, both seasonally and potentially over periods of many years. We feel that a satellite record of the historical development of a country may yet prove to be one of its greatest attributes. As an illustration, Figs 1.1, 1.2, and 1.3 are LANDSAT I and II colour composite prints covering the South Island high country from Mount Cook to the Waitaki Basin. Fig. 1.1 was taken in December 1973, Fig. 1.2 in October 1975, and Fig. 1.3 in April 1977. The suspended sediment in the lake and river systems is traceable by its light blue colour, and the seasonal variation can be clearly seen. The differences in lake

levels, particularly in Lake Pukaki (light blue), can also be detected, as can other more subtle short- and long-term variations.

For operational use of LANDSAT data, the probability of obtaining cloud-free data must be improved, and timely reception becomes a necessity. Access to a number of satellites in orbits which are separated by, for instance, the 6-day periods planned for LANDSATS I, II, and III, will greatly increase the chance of cloud-free cover. A local receiving station is the only means of receiving data in "real time" and of achieving the greater coverage required. This subject is discussed in Section 1.7.2 and Chapter 2.

## 1.5 SUMMARY OF DISCIPLINE INVESTIGATIONS

The major projects, achievements, and problems of the investigating groups in each discipline are briefly outlined here. For detailed discussions the reader should refer to the appropriate chapter.

### 1.5.1 CARTOGRAPHY

The orthogonal nature of the LANDSAT system-corrected image and its relative freedom from height distortion have obvious implications for cartography. Without further geometric correction, the Department of Lands and Survey (Chapter 14) has used system-corrected imagery as a model for hill-shading in a new series of relief maps and aeronautical charts. These are at scales of 1:250,000 and 1:500,000.

The same imagery has been used to augment and update the data base for the new 1:250,000 scale metric map series. A "whole country" map at 1:2,000,000 is also being produced with the aid of LANDSAT data, although this is being hampered by lack of complete coverage.

It has been established that LANDSAT can help in the mapping and accurate positioning of New Zealand's offshore islands. Further work on this project, however, awaits the production from CCTs of detailed imagery using the recently ordered "colorwrite" machine, and geometrically corrected to fit the desired map projection (Chapter 8).

Chapter 13 describes experiments with a mirror reflector similar to the type reported by Evans (1974), in which the sun's rays are deflected into the path of the satellite; and if the mirror is sited at a precisely known ground location, it can serve as a ground control point for image rectification. The Department of Lands and Survey is considering the application of LANDSAT imagery to Antarctic mapping, and the mirror reflector might be of particular significance in this context.

We feel that this two-year investigation has demonstrated some real cartographic applications for LANDSAT data in New Zealand. Much greater use could, however, be made of imagery with higher resolution to supplement and update the data base for larger scale maps. Complete coverage would also be needed on possibly an annual or bi-annual basis.

### 1.5.2 LAND-USE AND VEGETATION MAPPING

Periodic land-use and vegetation surveys are very important in this agricultural and pastoral country. If Earth resources satellite data becomes operationally useful in this discipline, the result could be large savings in manpower and the time required to survey a given area. Surveys are under way or planned for the King country (west of Lake Taupo, N.I.) and the Waitaki Basin and Westland (S.I.). Three organisations have been assessing LANDSAT imagery for these and other surveys: the Department of Lands and Survey (Chapter 14), the Ministry of Works and Development (MOWD) (Chapter 17), and the Geography Department of the University of Auckland (Chapter 18).

The findings of the three groups differ considerably in detail, but the general consensus of these and other contributions indicates that up to eleven major land-use categories can readily be distinguished on LANDSAT imagery. These are: urban areas, indigenous forest, exotic forest, scrub, pasture, crops, bare soil, water, tussock grassland, bare rock, and snow. The differences between findings occur in the subdivision of these major categories, and this is probably due in part to the different techniques and data products employed by each group. Colour additive prints derived at PEL from the EROS transparencies have been used by all three groups, but in addition the University group has used colour "density sliced" imagery and coded lineprinter output from the CCTs. The MOWD contributions are based on computer-generated "thematic maps" and prints from the "Image 100" analyses at Sioux Falls, South Dakota. They are particularly concerned with the potential of LANDSAT imagery to update the MOWD Land Resource Inventory Worksheets which cover the whole country.

There is no doubt that sub-classifications within some of these major categories can often be clearly identified, and the papers on forestry, agriculture, and hydrology indicate the extent to which this might be possible.

One of the best data products assessed by these groups appears to be the colour composite enhancements photographed from the screen of the "Image 100" interactive computer/analyser. Imagery of this type can also be produced on the "colorwrite" machine soon to be available at PEL, and we feel that such imagery might prove to be most useful for the "man in the field".

Identification and mapping of the sub-classifications within a major category have been hampered by extraneous variables such as terrain, slope and aspect, soil and moisture regimes, etc. A better understanding of their effect on spectral signatures is needed before more progress can be made. Mapping of other features such as soil erosion is limited by the present spacecraft resolution.

### 1.5.3 GEOLOGY

A summary of all the LANDSAT investigations by the N.Z. Geological Survey is given in the introduction to Chapter 15 by



Dr R. P. Suggate. Some brief comments on topics discussed in this and earlier reports follow.

A major part of the activity of this group has been in the detection and mapping of lineaments. In this respect the most generally successful products were positive prints and transparencies of MSS band 6 or MSS band 7. The complementary nature of images with high and low sun elevation angles is pointed out in Chapter 15 and in the fourth quarterly report to NASA (PEL no. 568). The low angle (winter) images were of particular benefit in identifying sets of parallel minor lineaments in areas of low topographical relief, but were less useful in rugged terrain where shadowing obscured many features. High sun angles gave more detail in, for instance, the Southern Alps, and in some cases allowed major lithologic units to be detected.

LANDSAT imagery has been found to be better than aircraft imagery for studying geomorphological patterns in sedimentary rocks, and further studies involving Quaternary deposits are planned.

A two-colour composite from transparencies of MSS band 4 (negative) and MSS band 7 (positive) has been shown to highlight active faults, apparently due to the differential reflectivity in these bands, of water in the fault crush zones.

It is also pointed out that lineaments are of limited use in mineral detection in New Zealand except for a few specific cases.

The geothermal and volcanologic investigations originally planned for LANDSAT II were not possible in the absence of the MSS thermal band. It is hoped that these investigations will become possible with the launch of LANDSAT C.

#### 1.5.4 FORESTRY

LANDSAT applications to forestry have been covered in a wide range of projects initiated by the Forest Service (Chapter 19) and the Forest Research Institute (Chapter 16).

In at least one project (19.7), the problem has been the comparatively simple one of identifying and mapping small areas of forest against the general background. This investigation of privately owned exotic forests in the North Island has clearly shown that seasonal variations in spectral signature are very significant, even in relatively "static" subjects such as ever-green trees. Identification of the exotic trees was much easier in a LANDSAT I colour composite of 23 December 1973, in dry summer conditions, than appeared to be the case with a late spring scene of 17 November 1975 from which the CCT data were used to produce thematic maps. This survey also suffered from inadequate image resolution, since many of the plots were smaller than 2 hectares. The Forest Research Institute report mentions also the need to determine the extent of seasonal variations.

Most of the other papers are concerned with the sub-classification of known forest areas, and with the investigation

of specific events such as the windthrow in Eyrewell State Forest (19.2), fire damage in Hammer State Forest (19.5), or the detection of the fungus disease dothistroma in Radiata pine in the Kaingaroa State Forest.

The mapping of indigenous forest is discussed in several papers (16, 18.1, 19.3, 19.6). The consensus indicates that forest species can be broadly classified if the areas involved are large enough and the species are not too diverse within each area. Many other features, however, can distort the spectral signature, such as slope, aspect, soil type and degree of canopy closure. Much more work is needed to identify and define factors which affect the spectral reflectance.

Deficiencies in the "normal" colour composite for forestry work have been pointed out. These are due to the low radiances associated with the target, leading to dark images with few discernible features. Some enhanced imagery has been produced specifically for forest interpretation, and the "colorwrite" machine should shortly make such enhancements routinely available to the New Zealand user.

Mixed success is reported in the other investigations. The big storm of August 1975 blew down 22% of the trees in Eyrewell State Forest. Of these windthrown areas, 86% were detected from enhanced LANDSAT imagery. However, subsequent efforts to monitor the desiccation rate of the fallen trees have not been successful. The Hammer fire has been surveyed only with our aircraft camera using LANDSAT type filters, and from these images the burnt, scorched, and undamaged areas were easily mapped. Attempts to correlate dothistroma with anomalies in spectral signature using colour composites and CCTs have not been successful so far.

We believe that LANDSAT has many applications in forestry, not the least of which is its potential ability to update the national data base routinely and rapidly. To be really effective, much more needs to be known about the spectral reflectance of the target, and many projects await the more detailed resolution planned for future spacecraft.

#### 1.5.5 AGRICULTURE

Although New Zealand depends to a large extent on agriculture, no study projects were initiated by agricultural scientists in this investigation programme.

The staff of the Remote Sensing Section at PEL therefore decided to establish an agricultural test site, both as a means of acquiring the data necessary to test the developing technology, and also to see how LANDSAT might be used to conduct crop inventories and to analyse crop and pasture stress on a regional basis. The test sites in Mid Canterbury were chosen for their wide variety of spectral signatures as originally seen in a LANDSAT I image, and because the fields are sufficiently large to be resolved by the LANDSAT MSS. The choice of the first test site at Darfield was also aided by advice from the Crop Research Division of DSIR.

These studies, described in Chapter 10, have utilised imagery and data from LANDSAT, from the PEL multispectral aircraft camera (Chapter 2), and from ground truth surveys of several hundred fields. In the last year, the site at Darfield has been supplemented by another site at Leeston, near the Rakaia River. The PEL ground truth team has been greatly assisted by the Canterbury farm advisory officers (of the Ministry of Agriculture and Fisheries) and by the enthusiastic co-operation of local farmers.

The project started well with the acquisition of a cloud-free winter scene in August 1975 and a spring scene in October 1975. Since then only one scene has been received, taken in February 1977 with cloud cover over the test sites. Simultaneous aircraft coverage of the Darfield site was obtained for the August overpass, and again within two weeks of the October overpass.

A colour composite print of the original LANDSAT I scene (December 1973) shows clearly the regional pattern of growth at this relatively dry time of the year, and this pattern has recently been found to correlate rather well with ground water measurements made in that area. We feel, therefore, that LANDSAT may be very useful for detecting regional crop stress patterns, although once again the many variables involved need to be isolated and their effects examined in more detail. Local forms of stress, such as crop disease occurring in patches, cannot generally be detected by LANDSAT because of the limited resolution.

The October 1975 scene has been used almost exclusively in the crop identification programme, since the other images have been taken at the wrong time of the year, or are lacking in ground truth. The scene has been analysed using colour composites, CCT data, and the "Image 100" interactive analyser. It is concluded that October is generally too early in the year for accurate crop identification, particularly of wheat and other cereals. Even so, in small areas around Darfield, wheat fields can be detected in the "Image 100" composites, and more plainly from the aircraft products. The variables, however, are too great to allow extrapolation from one area to another. The LANDSAT I December scene contains a much greater range of spectral signatures, and this time of the year may be more appropriate for this type of analysis. In all cases, major categories such as forest and bare ground can be mapped fairly easily.

We believe that although this programme has suffered for lack of seasonal imagery, it has provided a tantalising glimpse of the possibilities of routine mapping of crops and crop stress over large regions. The results to date can only be regarded as preliminary, and it is hoped that this work will continue through LANDSAT III and beyond. Considerable benefit would be derived from the participation of an agricultural scientist or plant physiologist in future work.

### 1.5.6 HYDROLOGY

By world standards, New Zealand has an abundant supply of water, and this is an important resource not only for agriculture but as a major source of electric power in this country. The ability of LANDSAT MSS band 4 to penetrate water enables studies to be made of water turbidity and other parameters in both coastal and freshwater areas. The variation of these parameters with depth can often be inferred from the differential penetration of the four bands. Snow, with its high reflectance, can also be seen and mapped on cloud-free images.

The Auckland University group (Chapter 18) has analysed coastal turbidity and sediment flow in two North Island coastal regions, and conducted a preliminary study of Lake Taupo, New Zealand's largest freshwater lake. These analyses utilise MSS band 4 only and are derived from colour "density sliced" images and CCT coded or "shaded" outputs from the lineprinter. The studies demonstrate that suspended sediment can be seen and mapped from LANDSAT and that coastal flow patterns are detectable. However, great care is needed to differentiate between suspended sediment and the sea or lake floor, and in many cases this cannot be done with certainty from a single image.

In Chapter 12, two LANDSAT scenes are used to map the motion of suspended sediment in a tidal basin. In this case, comparison of the two scenes taken at different states of the tide, and the multiband approach, allow some of the sediment motion to be distinguished from the bottom siltation features. The penetration depths of MSS bands 5 and 6 were also estimated for the sediment-laden waters of this inlet.

The hydro-electric power system in this country depends to a great extent on melting snow to recharge the hydro-lakes. LANDSAT scenes of the South Island have shown that a cloud-free image can be used to measure the projected area of snow cover over a very large region. The relation between this area and the available water has not been established, however, and it is hoped that future investigation programmes may include studies of this problem.

At the request of the National Parks Authority, a study of snow cover has been conducted in the Nelson Lakes National Park (Chapter 11), in connection with a proposed new skifield. The PEL group and the Forest Service have collaborated to try to related LANDSAT spectral signatures to snow quality. The results again show that timely LANDSAT imagery is useful for recording projected area and seasonal changes, and that the observed differences in spectral signature might enable snow to be broadly classified for its surface characteristics. As with other investigations, more work is required to isolate the variables and to confirm the extent to which LANDSAT data can be used.

We are optimistic about the future possibilities of using spacecraft data to monitor water and snow parameters in New Zealand, providing that timely coverage is available, and that

higher resolution imagery can be received in this country, to increase the scope and application of this new technique.

## 1.6 FUNDAMENTAL STUDIES AND TECHNOLOGY DEVELOPMENT

Remote sensing depends as much on physics and technology as on the interpretative expertise of earth scientists. Any country becoming involved in this interdisciplinary branch of science needs at least one physics and engineering "base" to assist imagery users and to keep abreast of new techniques. In New Zealand at present this function is fulfilled by the Remote Sensing Section at PEL.

The capital expenditure for this exercise has been modest. Great use has been made of the many facilities already existing at PEL, and these cover the subjects of optics, photometry, mechanical design, electronics, computing services, and instrument engineering.

In the two-year investigation period, studies of the more fundamental topics have included LANDSAT radiometry (Chapter 3) and atmospheric effects (Chapter 4). Technological developments can be divided into data acquisition (Chapter 2), image processing (Chapters 5, 6, 7, and 8), and the development of an interpretation laboratory.

For some purposes, there is an obvious need for large-scale "underflight" imagery, either to complement LANDSAT or because very high resolution is essential. The four-Hasselblad camera system (Chapter 2) with its inbuilt "calibration" radiometers has operated very successfully during this programme. However, there is still difficulty in correlating photographic density with target radiance, and a contract has recently been let with the Electrical Engineering Department of the University of Canterbury to study recent developments in aircraft electronic scanners; with a view to obtaining imagery directly in digital form.

All aircraft and ground truth measurements in this programme have utilised the LANDSAT MSS bandpasses. This has enabled the results to be compared with LANDSAT data, although the dangers in this procedure are pointed out in Chapter 3.

A real understanding has yet to be gained of the spectral reflectance of targets in New Zealand and the way in which they change with season, sun angle, and other parameters. To this end, a field spectrometer is being completed which will enable measurements of continuous spectra to be made, and may influence the choice of the spectral bandpasses used in future surveys.

Image processing started with the building of a photographic processing laboratory (Chapter 5). The expertise developed in this laboratory has greatly influenced the activities of the Section, and most of the pictures in this report are examples of its work. To have control over the quality and variety of photographic products is, in our opinion, fundamentally important to the progress of this type of investigation.

Imagery in its digital form has obvious advantages for detailed interpretative work and for enhancing scenes before their subsequent reproduction as a photograph. Our aim has been to make digital radiance data and computer-enhanced imagery available to users, and to encourage users to become familiar with interactive computer analysis of CCTs. In the latter case, this is being achieved by making CCT data, and "cluster analysis" and other programs, available on a large computer network with nationwide terminals (Chapter 6). This also has the capacity to reformat and process a complete LANDSAT scene.

The smaller computers at PEL (Chapter 7) are used for more detailed development work with smaller sub-scenes from LANDSAT. A package of programs enables images to be dynamically "stretched", ratioed, or otherwise enhanced before being "rewritten" into photographic form. Much can be learned by combining imagery not only as a colour composite of different spectral bands, but also as a composite of imagery taken at different times and possibly even from different satellites. To do this, the images must be geometrically corrected to fit a common co-ordinate system, and this is also a requirement for cartographic applications. A set of computer programs has been completed (Chapter 8) in which any LANDSAT image can be corrected to fit a specified map projection.

The resolution limits of the present LANDSAT digital data have been explored in Chapter 9 by a study of the ships in Cook Strait. Even with the present MSS pixel size (80 x 60 m), it is shown that larger ships can be detected in clear conditions and that the different responses of the MSS bands can be used to infer the direction and speed of a ship. This indicates what might become possible with the advent of "SEASAT" and higher resolution LANDSAT instruments.

The interpretative equipment at PEL available to users is described in Chapter 2. Individuals and "discipline" groups are encouraged to use the computing, density slicing, additive viewing, and other facilities as the need arises. It is hoped that this facility might expand into an "intralab" of the type set up at the Goddard Space Flight Center.

In spite of the limitations imposed by lack of size and limited budget, it is believed that for a small country the approach to remote sensing technology described here is worthy of consideration, and should be pursued further.

## 1.7 THE FUTURE

### 1.7.1 FUTURE SPACECRAFT

The third LANDSAT satellite, LANDSAT C, is due for launch on 29 September 1977. This spacecraft will have an identical Multi-Spectral Scanner to that on LANDSAT II, with the addition of a fifth "thermal" spectral band of reduced resolution. The other instrument, the Return Beam Vidicon (RBV), will have a single "panchromatic" band of 40 m resolution. These and other satellite instruments are briefly described in Chapter 2.

A "statement of interest" has been compiled and sent to NASA, in which thirteen agencies in New Zealand have expressed their desire to use data from this satellite. Imagery from the "existing" MSS bands, if available, may enable more positive conclusions to be drawn from projects already in hand. The "thermal" infrared band may provide the first synoptic view of this country's extensive geothermal regions. The RBV imagery should help users to assess the gains to be made in, for instance, urban monitoring and cartography by going to this higher resolution.

LANDSAT C is believed to be the last of the Earth resources series in which data from the major instruments is recorded by the on-board tape recorder. LANDSAT D, with the "thematic mapper" of 30 m resolution and with six spectral bands, will probably be launched in 1980-81, and outside of the USA, data will be available only to the user with access to a "local" receiving station.

The first of the "SEASAT" series is due to be launched in 1978, and will monitor ocean resources with a variety of "active" microwave instruments (Chapter 2). Of particular interest is the potential ability to detect fishing areas in coastal and distant water regions. The Synthetic Aperture Radar (SAR), with its 25 m resolution and cloud penetration properties, has applications in sea-state monitoring, search and rescue, and ship detection. Other spacecraft with Earth resources applications include some of the future Nimbus series and the planned Applications Explorer series.

Beyond LANDSAT D, plans for LANDSAT type spacecraft include instruments with even higher resolution and which can be "pointed" to cover selected scenes of reduced area.

#### 1.7.2 A NEW ZEALAND RECEIVING STATION

Fig. 2.3 shows the coverage which would be available to a "local" receiving station for Earth Observation Satellites, if it is sited at Wellington. It shows that only a centrally disposed station is capable of covering the whole country including the new "Exclusive Economic Zone" (EEZ). Now that the decision has been made to site the Australian station at Alice Springs, there is no possibility of even a part of New Zealand being covered from a station outside this country.

A correctly designed receiving station would be able to receive data from all the satellites mentioned in 1.7.1. This "real time" capability to access a satellite as it passes overhead means that data can be acquired from each satellite in a series at much more frequent intervals than at present. The chances of obtaining cloud-free images for any give area are thereby greatly improved, and the data are timely enough to be of operational use.

The construction costs for the planned Australian station are quoted as \$4.2 million, and for New Zealand it is expected

that the costs would be of the same order. The operating costs would involve "rental" fees for each satellite series, which for LANDSAT and SEASAT might total about \$400,000 per annum. A staff of 22 people is envisaged for the Australian station, and they would be responsible for image processing and dissemination as well as operating the receiver itself.

### 1.7.3 COST-BENEFITS

The question of cost-effectiveness of Earth Observation Satellites is often raised, and is especially significant when the merits of a local receiving station are being considered.

The present-day costs of LANDSAT imagery bought from the USA amount to \$200 per scene if digital data are used. This covers 34,000 sq. km, giving a cost per sq. km of 0.58 cents. The same area flown by aircraft at an image scale of 1:50,000 would cost \$170,000 at the present rates of \$5 per sq. km. In many cases, of course, the higher resolution of aircraft imagery is essential, although whole-country coverage by aircraft is only achieved over a period of years. LANDSAT and aircraft imagery are therefore seen to be complementary, the large area coverage and "updating capability" of one being offset by the higher resolution of the other. For a country with a local receiving station, the per sq. km cost of spacecraft imagery will depend on the number of useful scenes received per annum. In general this cost is likely to be higher than for the "purchased" product, but against this must be set the timeliness, frequency, and improved resolution that will not be available by other means.

No serious attempts to assess the potential cost-benefits of Earth observation spacecraft have so far been made in this country. The disciplines of economic significance can be seen from section 1.2, and of these, agriculture, forestry, and the expanding fishing interests should perhaps be singled out for attention. One obvious area in which timely information might be financially beneficial is crop yield prediction, in which a crop area inventory is combined with the observed regional stress factors. Studies in the USA have shown that yield should be predictable, and the Large Area Crop Inventory Experiment (LACIE) is designed to predict yield on a world wide basis.

The advent of SEASAT could increase the economic potential considerably. The cost-benefit predictions for the USA indicate that the integrated benefits accruing from SEASAT in the period 1985-2000 lie between \$802 million and \$2670 million (NASA 275-125).

It is suggested that the next investigation period in New Zealand should include a project to assess the potential cost-benefits of all relevant spacecraft data in each of the major economic areas. This will involve the participation of key people in all of these disciplines, if the resulting figures are to be at all meaningful.



## 1.8 CONCLUSIONS

The New Zealand economy depends to a large extent on agricultural and other land-related activities. We believe, therefore, that the possibility of monitoring our environment from spacecraft has a special significance. The LANDSAT II programme has shown that applications exist in agriculture, forestry, cartography, hydrology, land use and vegetation mapping, and perhaps to a less extent in geology and in urban development monitoring.

We feel that the greatest uses of Earth observation spacecraft will probably lie in their ability to detect and record change over large areas. This is true for both short-term "seasonal" change and for long-term "secular" change. It is therefore essential that a proposed operational system should be capable of fairly frequent repetitive coverage, and that the imagery should become rapidly available to local users. The high incidence of cloud cover in New Zealand greatly impedes the chances of obtaining coverage from a single spacecraft with an 18-day orbital cycle. Access to more than one spacecraft will reduce the cycle time and give a much better chance of obtaining cloud-free imagery.

Many of the investigation reports have mentioned the need for imagery with increased resolution. This is largely due to the small size of the targets in this country, and to the wide diversity of spectral signatures intermixed within a small region. We look forward to the higher resolution imagery planned for future spacecraft, and hope that New Zealand will be in a position to make use of it.

The two criteria of frequent coverage and increased resolution will probably be satisfied only if a receiving station is built in this country (section 1.7.2). This would result in large volumes of data becoming available from several series of satellites. We feel that this approach is very worthy of consideration, and should be viewed as a "total concept". This implies that all possible data types and applications should be considered when assessing the merits of such a local station. Moreover, the associated problems of data acquisition, data storage, retrieval and dissemination, and image processing and display should be treated as a whole. Indeed, a greater part of the cost of a receiving station would be in the equipment to process the data and make it available to the user in a timely manner.

We believe that the LANDSAT II investigation has made a promising start to this new means of viewing our environment, and we look forward to continuing this work with LANDSAT III and beyond.

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APPENDIX

## COMMUNICATIONS

In an isolated country like New Zealand, communication can be a problem, especially in a co-operative project with an overseas organisation. We have therefore been fortunate to have access to the "Peacesat" geostationary satellite communications link, which has a terminal at Wellington Polytechnic. Throughout the duration of the LANDSAT investigations, we have been able to hold informal discussions of up to 1-1/2 hours duration with LANDSAT project personnel at the NASA Goddard Space Flight Center, Maryland.

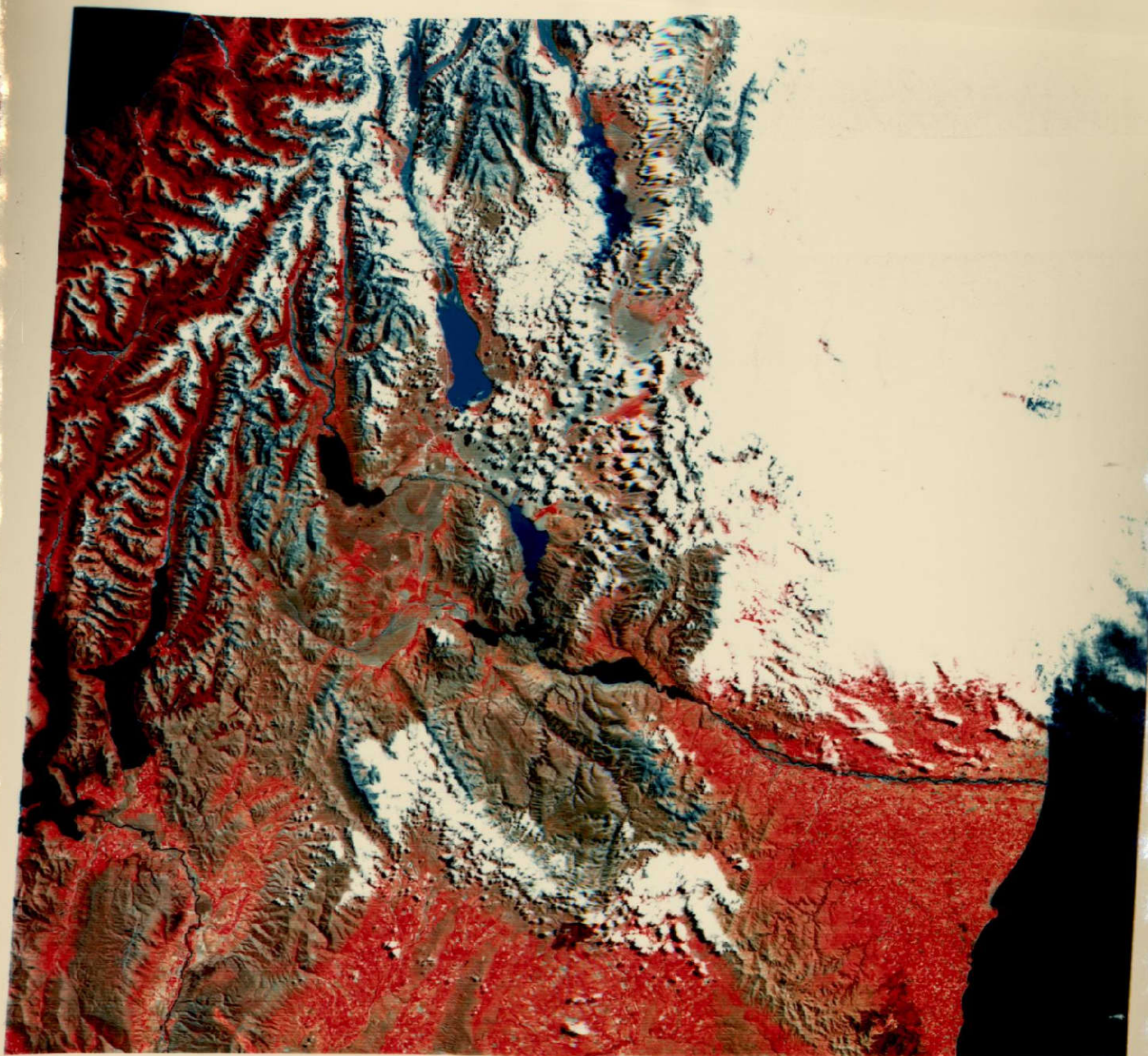
These discussions have covered the progress of the New Zealand projects, and made people in this country very much more aware of the extent of the NASA involvement in Earth observation satellites and their plans for the future. "Peacesat" is used for communications between many of the Pacific islands, and several groups in these islands have participated in the LANDSAT meetings. The result has been an increase of interest among island groups, with at least one Peacesat session arranged specifically to try to answer some of their queries.

The LANDSAT programme has prompted the generation of a Remote Sensing Newsletter by the PEL group, and this is now circulated to more than 240 destinations in New Zealand and overseas, including the Pacific islands.

Within New Zealand itself, interest in satellite remote sensing has been reinforced by over 60 lectures given by PEL staff, and many others given by members of "user" organisations. LANDSAT displays and exhibitions now total more than 10, and a workshop on remote sensing technology is planned at PEL for the early months of 1978.

These investigations have thus helped to create a climate in which more people will wish to use the data in a wider variety of applications.





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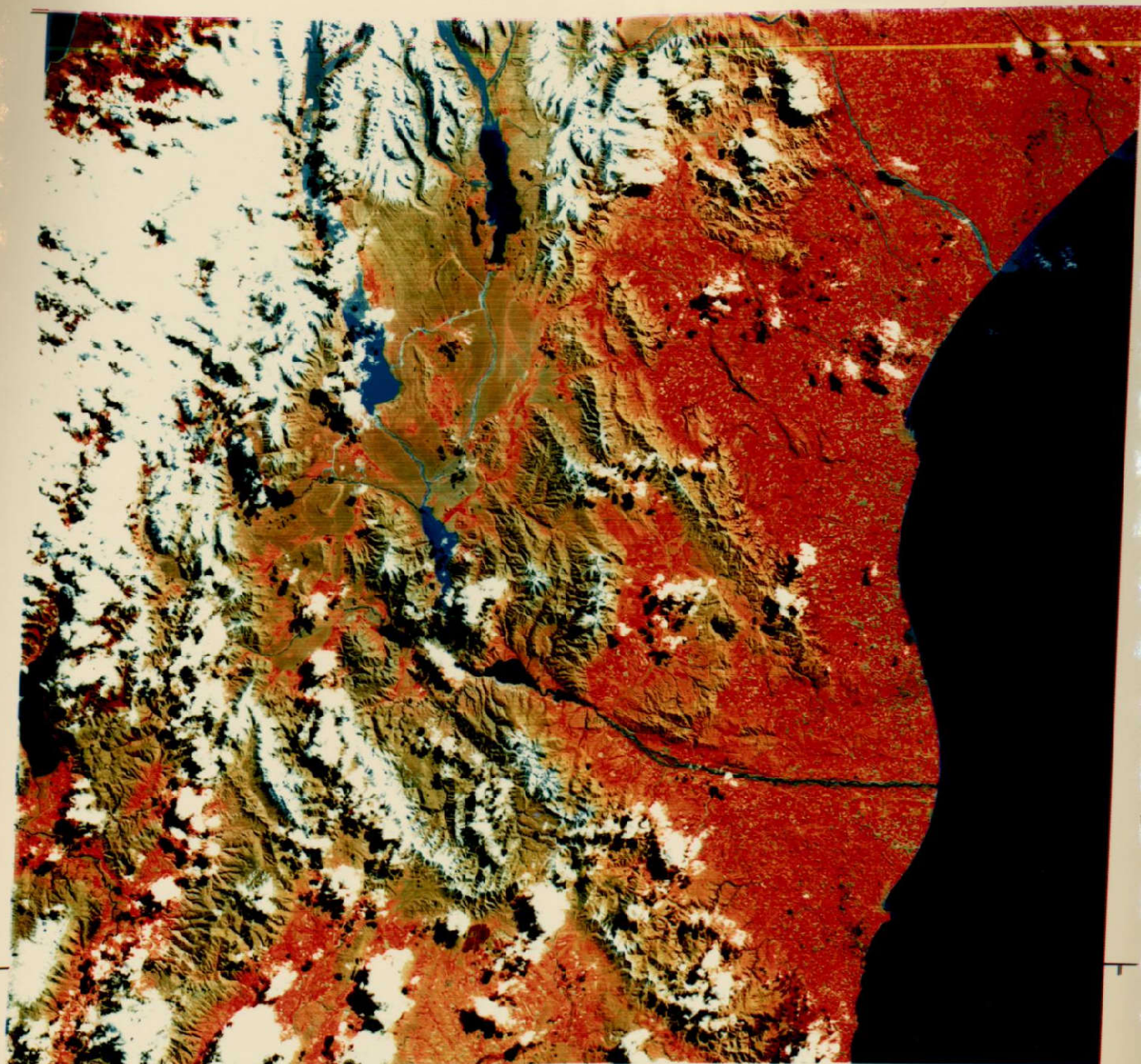
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Fig. 1.1 Change Detection  
Central South Island from LANDSAT I in summer - December 1973

Suspended sediment in lake and river systems appears in blue, east coast agricultural and pastoral areas in red, indigenous bush and forest in red/brown. High sun angle reduces shadowing and permits valley floors to be clearly seen.

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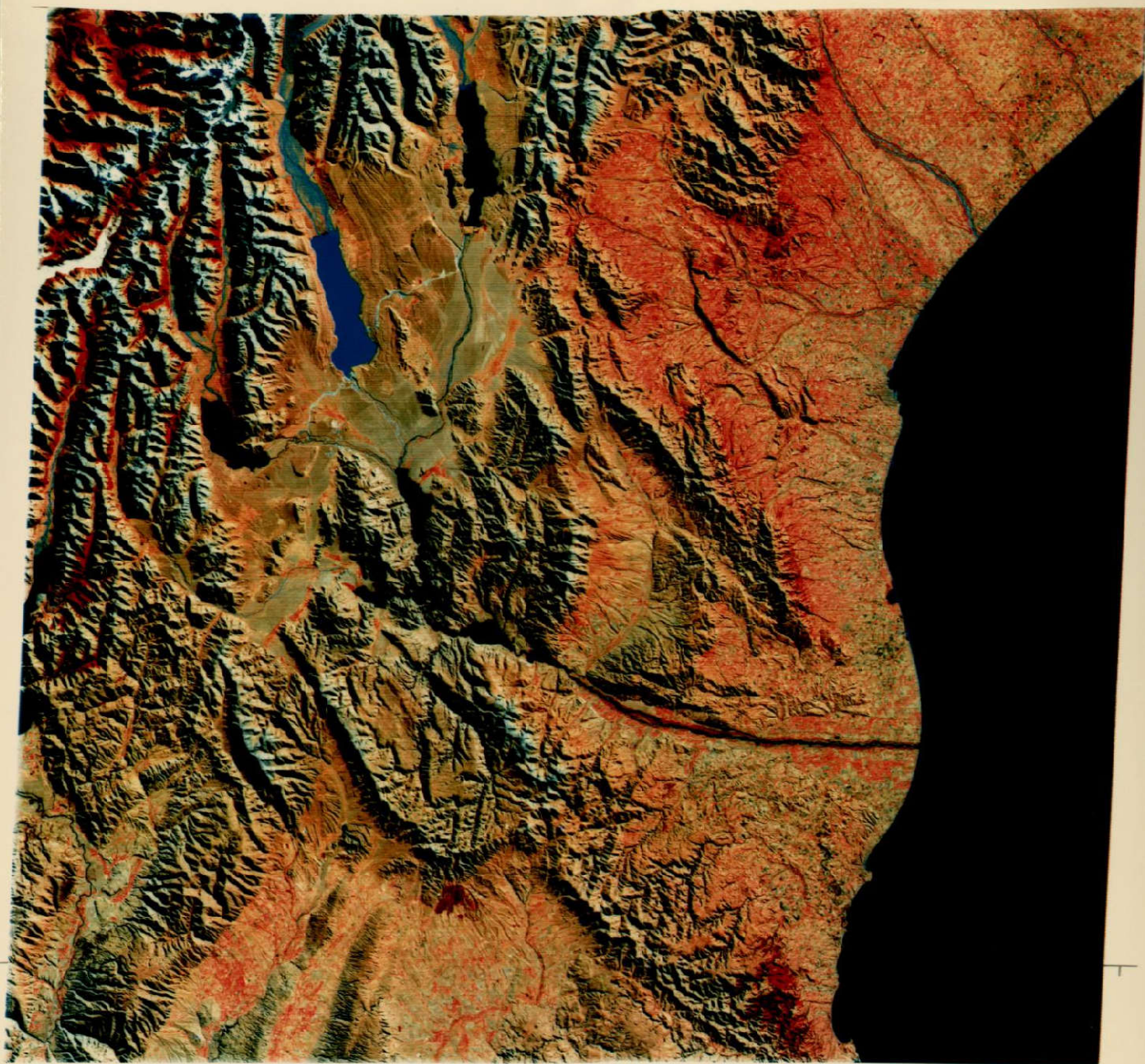


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Fig. 1.2 Change Detection  
 Central South Island from LANDSAT II in Spring - October 1975

Intensified red colour of east coast agricultural areas signifies period of vigorous growth. Sediment discharges from east coast rivers and into Lake Takapo (top centre) can be seen.





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Fig. 1.3 Change Detection  
 Central South Island from LANDSAT II in Autumn ~ April 1977

Topographic features stand out due to low sun angle. Note the reduced vigour of growth in agricultural areas and decrease in lake and river sediment. The level of Lake Pukaki (top centre-left) has increased significantly over previous scenes.

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## CHAPTER 2

## DATA ACQUISITION AND DISTRIBUTION

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ABSTRACT

Data acquired by the Remote Sensing Section of the Physics and Engineering Laboratory, DSIR, are reviewed. Details are given of how the data have been obtained, how they have been catalogued, and how they may be obtained by other users within New Zealand. Data likely to become available in future are outlined.



## 2.1 INTRODUCTION

Since 1975, the Remote Sensing Section of the Physics and Engineering Laboratory, DSIR, has been acquiring and distributing an extensive amount of New Zealand remote sensing data. This chapter describes the data, how they have been obtained and catalogued, and how they are being made available to other users within New Zealand. Where a part of this subject has been dealt with in another chapter of this report, reference is made to that chapter rather than repeating the discussion here. Finally, remote sensing data likely to become available within New Zealand in future are outlined.

Data acquired by the Remote Sensing Section have come from the multispectral scanner (MSS) on LANDSATS I and II, our aircraft multispectral survey program, and a number of instruments purchased for, or developed by, PEL. These are dealt with in turn.

## 2.2. LANDSAT IMAGERY

### 2.2.1 Technical Details

Each image of New Zealand taken by the LANDSAT MSS is recorded on an on-board tape recorder and later transmitted to a ground receiving station in America where the data are stored on a set of high-density computer tapes. Two types of LANDSAT data products are being regularly received at PEL, which has been acting as a dissemination centre for LANDSAT imagery of New Zealand. NASA processing of the high-density computer tapes yields either monochrome photographic images produced on an "electron beam recorder", or digital data stored on a set of computer compatible tapes (CCTs).

The detailed specifications of the LANDSAT data are given in the LANDSAT Data Users Handbook and further detail on the CCT format is given by Thomas (1975). In addition, pertinent aspects of these specifications are mentioned in chapters 3, 5, 6, and 7. In brief, each LANDSAT image (see for example Fig. 5.4) covers a 185 km square area and is taken through four different spectral filters. The four resultant image bands (called MSS bands 4, 5, 6, and 7) are taken through nominal filter passbands of 500-600, 600-700, 700-800, and 800-1100 nm respectively. This gives a green, a red, and two near-infrared image bands. Each single MSS band, CCT image consists of a matrix of approximately 2340 x 3264 picture elements or pixels. Each pixel corresponds to a 79 m square ground area.

Normally a colour composite LANDSAT image such as that in Fig. 5.4 is produced by using our colour additive viewer (chapter 5) to project negatives of MSS bands 4, 5, and 7 through blue, green, and red filters respectively on to colour photographic paper. Each LANDSAT negative uses the central 2256 of the 2340 rows in the corresponding CCT image.

The times at which the LANDSAT MSS is switched on are controlled by NASA and are limited by the power available on the satellite and the storage capacity of the on-board tape recorder.

As the LANDSAT MSS bands cannot penetrate cloud, it is desirable that the MSS should be switched on only over areas which are largely cloud free. To try to achieve this, weather forecasts derived from meteorological satellites are used in scheduling LANDSAT coverage.

Some LANDSAT I coverage of New Zealand was made during late 1973 and early 1974 in response to a special request from PEL. Because of our involvement in the LANDSAT II investigation program, LANDSAT II coverage of New Zealand has been received more regularly since August 1975. The main limitations on this coverage have been the cloudy conditions common in New Zealand and more recently the need to conserve the one remaining tape recorder aboard LANDSAT II. We no longer receive coverage from LANDSAT I, as the on-board tape recorders have failed. However, real-time coverage of New Zealand could be received from both LANDSAT I and II if a suitable receiving station were available in New Zealand.

### 2.2.2 Transparencies

Sets of photographic transparencies for each LANDSAT scene of New Zealand are received from the EROS Data Center, South Dakota, on a standing order basis, if the cloud cover is less than 30%. These negatives, which are about 70 or 240 mm square, are usually received about two months after the corresponding satellite overpass. Each scene is then allocated a sequential PEL identification number, and relevant details about it are recorded in our filing system. As soon as this has been done (usually within 24 hours) a set of 70 mm negatives is forwarded to each of our co-investigators.

PEL scene identification numbers are allocated sequentially. Numbers from 1 to 99 and from 200 to 899 are reserved for LANDSAT II scenes; numbers from 100 to 199 are reserved for LANDSAT I; and numbers from 900 to 999 are kept for scenes which are not of New Zealand.

For each scene, one set of 70 mm positive and negative transparencies is filed within cellophane jackets inside transparent plastic file sheets in a book at PEL. The 240 mm transparencies are filed in a cabinet according to the PEL sequential identification number.

The Department of Lands and Survey (see chapter 14) uses its 70 mm negatives to provide black and white LANDSAT prints to meet other requests for LANDSAT imagery; its quick-look prints are particularly widely circulated. At present, requirements for colour-composited LANDSAT imagery are met by PEL.

### 2.2.3 CCTs

CCTs, if required, are ordered only after the corresponding transparencies have been received and evaluated. They generally take about three months to arrive from the EROS Data Center. The CCTs are then catalogued, and two copies of them are made on the IBM 370/168 computer network (see chapter 6). One copy is for



use on the IBM 370/168 and the other for use in our "in-house" computer system (see chapter 7). The original CCTs are then stored as an archival data set. CCT processing is being carried out only at PEL as described in chapters 6 and 7. An increasing demand for computer-processed imagery is expected once our colorwrite device for outputting images from the computer (see chapter 7) becomes operational.

An increasingly time consuming problem is determining which imagery is most applicable to a particular user's investigation. To facilitate search of our growing data base for applicable imagery, a Rapid Imagery Location Indexing System (RILIS) has been developed for use on the local HP 2100 computer programmed in the Time Shared Basic language system. Searches of the data base may be initiated on a geographic or temporal basis. The scene identification number, etc., is returned by the computer to the inquirer. Unfortunately other priorities in this LANDSAT program have necessitated this data bank maintenance lagging behind the actual data catalogue. This will be shortly rectified. (This RILIS package is described further in the two PEL reports by I. L. Thomas and P. J. Ellis Nos 516 and 517 April 1976.)

#### 2.2.4 LANDSAT DATA PRODUCTS RECEIVED

The LANDSAT I and II photographic products listed in Tables 2.1 and 2.2 have been received at PEL. As investigators often support LANDSAT II studies with LANDSAT I data, the complete catalogue is included in this LANDSAT II report.

A map index system was developed early in the study to permit the geographic location of the scene centre point to be rapidly described in terms of day number in the 18-day satellite orbital cycle and position along the orbital track from an arbitrary latitude north of New Zealand. This index map is presented as Fig. 2.1. The index locations used here may be related to the subsequently advised NASA Path and Row numbering by noting that Day Number 4 in the cycle is equivalent to Path Number 075 and Day Number 9 is equivalent to Path Number 080. Similarly Track Number 1 is equivalent to Row Number 085 and Track Number 6 is equivalent to Row Number 090.

As the need arises CCT products are ordered and are made available through local computing systems. A list of these products acquired, or ordered, to 1 September 1977 is given in Table 2.3. This will give cloud-free CCT coverage of almost all of New Zealand.

### 2.3 AIRCRAFT MULTISPECTRAL SURVEY PROGRAM

#### 2.3.1 Overview

The Remote Sensing Section, PEL, has, since 1974, been operating an aircraft multispectral survey program in conjunction with our LANDSAT investigation program. These surveys have been carried out using the four-camera Hasselblad multispectral system developed for this purpose at PEL (see Fig. 2.2). The

camera has been mainly flown in the Beechcraft and Aero Commander aircraft operated by the New Zealand Aerial Mapping Company. More recently some surveys have been flown in the Cessna 185 belonging to Aero Surveys Limited, Tauranga. The filters in the four cameras are nominally the same as those for LANDSAT (see chapter 3).

The multispectral surveys which we have flown over the last three years are listed in Table 2.4. Apart from test flights, most of these surveys were intended to provide information about our agricultural test sites at Darfield and more recently Leeston. An example aircraft multispectral image of the Darfield area colour composited at PEL is shown in Fig. 10.4. This agricultural imagery was primarily intended to extend our ground truth data (discussed in 2.4) and thus to aid in the interpretation of LANDSAT imagery. For this reason, aircraft surveys were arranged where possible to coincide with a LANDSAT overpass. Although we had no guarantee that LANDSAT would be switched on for those particular overpasses, our surveys on 2 August 1975 and 31 October 1975 (GMT) did coincide with LANDSAT coverage to within 30 minutes. Unfortunately the latter survey had to be reflown on 13 November 1975 (GMT). Analysis of the agricultural imagery is discussed in chapter 10.

A number of other surveys have been flown to help other user groups to become familiar with the use of multispectral aircraft imagery, which is more suitable than LANDSAT imagery for tasks requiring high resolution. These surveys have mainly been of forest areas and harbours and will not be discussed further here. It is hoped that this type of imagery will be of increasing use to the Department of Lands and Survey for land use inventory studies.

### 2.3.2 Technical Details

Fig. 2.2 shows the four-camera Hasselblad multispectral system developed at PEL. The hinged camera can be withdrawn from the camera viewing port until required for operation, and the system has built-in anti-vibration mounts and drift correction. Each camera is fitted with a multilayer interference filter defining the MSS spectral bands. At present we are using Tri-X (Kodak 2403 aerographic) for MSS bands 4 and 5, and Kodak 2424 aerographic film for bands 6 and 7. As the aircraft used in our surveys are unpressurised, it was found necessary to supply heated air to the cameras to maintain a constant temperature environment for the camera and film. This avoids variations in shutter speed, and film sensitivity, and reduces electrostatic discharges as the film advances.

An additional measure adopted was to winterise all moving camera mechanisms with a low-temperature lubricant.

It is intended to use the flying spot scanner developed by the PEL Electronics Section to digitise much of the seasonal aircraft coverage we have of our Darfield test site. These

images will then be analysed in the computer using the processing system discussed in chapter 7. The main problem with digitising imagery recorded on photographic film is to establish the relation between image density and target radiance in each spectral band. Rather than trying to reduce the variables associated with film processing, we have elected to measure target radiance at the time of flight. Mounted in the viewing plane of each single-lens reflex camera is a silicon photodiode and associated amplifier. The apertured detector views the target through the camera multilayer filter and has an instantaneous angular field of view of  $0.35^\circ$ .

For a test site survey conducted with the 100 mm Hasselblad lenses from a flying height of 20,800 ft above ground level, an image scale of one inch to one mile is achieved. At this scale, the radiometers view a 100 ft swath along the centre of each flight path, and this view is occulted for brief periods during film exposures. The idea of an in-camera radiometer was originally put forward by Mr Jonathan Cocks of DSIR Crop Research Division, Lincoln.

Each radiometer output is digitised and multiplexed on to a small cassette tape recorder. The data can then be input directly to our computer, or demultiplexed and visually displayed on an analog chart recorder. The digital cassette tape system was developed by the thick-film section of PEL Electronics Division.

The line scan, once stored in the computer, can be used to calibrate the scanned aircraft image so that it is linear in radiance. One such line scan was used in chapter 3 to check the radiometer calibration of our aircraft scanner against that of the LANDSAT MSS.

Some geometric distortion and scale variations between bands in our early aircraft imagery was due to misalignment of our lenses, and to variations in focal length in the unmatched 80 mm planar lenses we were then using. The effect of these distortions in the colour additive viewer is discussed in chapter 5. A matched set of 100 mm planar lenses is now in use in our Hasselblad camera system. Preliminary flight trials were conducted in May. The results have not yet been fully evaluated, but a first examination of the negatives indicates that the dependence of focal length on wavelength for each band may have been over-compensated, resulting in small scale differences with the lenses focused at infinity.

Those trials were the first in which the camera alignments were checked using the ray projector described in section 5.6. If the film planes of each camera are not plane parallel, the result is trapezium distortion and partial misregistration of the type experienced in the colour additive viewer. The ray projector was mounted on a flat base directly underneath the downward viewing camera, suspended at a height of 2 m above the base. With lenses and backs removed, small front-silvered mirrors were mounted on the reference surface forming the back of the

camera body. Alignment to an accuracy of better than 25 arc-seconds is then achieved using the procedure described in section 5.6.

### 2.3.3 Flight Planning

In planning a multispectral survey using our Hasselblad camera system the following independent factors must be considered to ensure that the recorded imagery will fulfil the objectives of the survey:

- (i) flying height above ground level,
- (ii) ground resolution and equivalent film resolution,
- (iii) area covered per 70 mm image frame,
- (iv) number of frames required for a given flight line.

For all our early surveys the lens aperture and exposure settings were set in flight from experience and depended both on the light level and the target. Recently a more precise method of setting the exposure has been developed. In the initial flight over the target area which is used primarily to determine drift settings for the camera, the camera radiometer (see. section 2.3.2) is used to measure the maximum and minimum radiances of the target in each spectral band. The corresponding exposure in each band is then read off a graph prepared on the basis of laboratory tests. This procedure will be used in future surveys.

For each survey the relevant data are recorded on a file sheet. Survey numbers for the PEL Hasselblad system are set up as follows:

MS - Multispectral  
 H - PEL Hasselblad camera system  
 n - survey sequential number  
 r - run number  
 f - frame number  
 b - band number

Then, on each negative transparency taken during survey number MSHn the following data are written (manually) on to the frame edge and allow it to be placed in the correct position in our image files: MSHnrfb.

The most frequently posed first question is the scale required on the film product. This is usually constrained by the requirement to match the imagery to other survey data.

For a camera of focal lengths  $f$  mm flying at an Above Ground Level (AGL) height of  $h$  feet, the required height  $h$  to give a desired scale  $S$  is obtained from the relation.

$$h \text{ (feet)} = 3.281 * 10^{-3} \quad f \text{ (mm)} * S$$

The scale S is defined such that S mm on the ground maps to 1 mm on the film product. Mixed units are employed through all the relations in this section, as these are the units in common practical use.

In the second column of Table 2.5 the AGL heights for a camera system with 100 mm focal length lenses are presented for a range of common scales on the photographic negatives.

### 2.3.3.2 Determination of the expected film resolution

The resolution of the system ( $R_s$ ) is derived from the resolution of the component items: film ( $R_f$ ), lens ( $R_l$ ), and image motion ( $R_i$ ) as follows:

$$\frac{1}{R_s} = \frac{1}{R_f} + \frac{1}{R_l} + \frac{1}{R_i} \quad (2.1)$$

(from Hellen 1971).

Kodak cite film resolution figures of 40 line pairs per mm (lp/mm) for their 2403 and 2424 products for a contrast ratio of 1000:1. The PEL f3.5 100 mm planar Hasselblad lens (Cat. No. 102111) has a resolution quoted by Hasselblad, of 40 lp/mm when stopped down to f8. Thus both  $R_f$  and  $R_l$  are taken to be 40 lp/mm.

$R_i$  is inversely related to the extent of the blurring due to aircraft movements. This depends on (a) the speed  $v$  (mph) of the aircraft relative to the ground, (b) the height  $h$  (feet) of the aircraft above the ground, (c) the focal length  $f$  (mm) of the lens, and (d) the exposure  $t$  (seconds). The extent of the blurring  $b$ , on the film is given by

$$b \text{ (mm)} = 1.467 \text{ fvt/h} \quad (2.2)$$

where the scaling factor is due to the mixed units. For the PEL system,  $f = 100$  mm,  $v = 100$  mph, and usually  $t = 1/250$  sec. Thus

$$R_i \text{ (lp/mm)} = 1/b = h/58.68 \quad (2.3)$$

$R_s$  may then be determined for different flying heights. Some example results including the equivalent ground resolution are given in Table 2.5.

Each image recorded on 70 mm photographic negative by our Hasselblad system is 54 mm square. For a given survey scale, the corresponding extent of the image side on the ground and the ground area covered can be quickly determined. Example results are presented in Table 2.6.

For most survey applications, a certain amount of overlap is required along a given flight line (e.g., to enable stereo viewing). An overlap of 60% between consecutive images has been routinely used in our surveys. In addition a side lap of 10 or 20% is also used.

In order to minimise the cooling problems mentioned in section 2.3.2, a couple of extra images are taken at the beginning of each flight line. The number of frames and the positioning of the flight lines are worked out using the above overlap and sidelap figures once the flying height and area to be covered have been decided.

All relevant details about each of our multispectral surveys have been recorded on sheets kept at PEL. These are useful for planning surveys, serve as a reminder sheet on board the aircraft, and assist when analysing the imagery.

## 2.4 DATA FROM OTHER INSTRUMENTS

In addition to LANDSAT and our aircraft program, we have been acquiring measured or processed data from a number of other instruments.

The colour isodensitometer (Datacolor 703) and colour additive viewer (International Imaging Systems Mini-Addcol Viewer model 6000) have both been used to process and analyse multispectral imagery as described in chapters 1, 5, 10, 11, 13, 17, 18, and 19. The colour isodensitometer can display density levels within a monochrome image as a different colour on a TV screen. The colour additive viewer is normally used to display (for viewing or printing), as a colour image, three monochrome images which have been taken through different spectral filters.

The Gamma Scientific model 820-10 radiometer has so far been used mainly for solar radiance and irradiance measurements as discussed in chapters 3 and 4.

A McKee-Pederson MP1018B scanning monochromator is being converted for use as a field spectrometer. It will be used to measure spectral reflectances of chosen targets for subsequent studies.

Another forthcoming device is an Optromics C4300 colorwrite machine for outputting images from magnetic tape to film. This device is discussed in section 2.2.3 and chapter 7.

A DSIR contract has been arranged with a research team headed by Professor R.H.T. Bates of the Department of Electrical Engineering, University of Canterbury, to evaluate the use of scanning devices (such as Charge Coupled Devices (CCDs)) in our aircraft program. The use of such devices should extend our aircraft multispectral survey capability.

A large amount of ground truth data has been gathered in conjunction with the aircraft multispectral surveys of our agricultural test sites. These data are discussed in chapter 10. A number of farmers in the Darfield-Leeston area (over 35 for our last survey) have been co-operating with us. At the time of each survey, a member of our section visits each farmer and prepares a ground truth map of the farm showing such details as crop type, height, condition, and previous treatment for each field.



## 2.5 FORTHCOMING SATELLITE DEVELOPMENTS

Over the next few years, remote sensing imagery of New Zealand may become available from a number of forthcoming satellites. Of particular interest are LANDSAT C, LANDSAT D, and SEASAT A. The applications and significance of these satellites for New Zealand are discussed in chapter 1. Relevant technical details about these satellites are given in this section.

LANDSAT C will have an on-board tape recorder so that images can be recorded for later transmission to a ground receiving station in America or elsewhere. We should therefore be able to receive imagery from LANDSAT C in the same way that we have received it from LANDSATS I and II. We understand that other planned satellites, however, will not record imagery. This means that we will be able to obtain imagery from LANDSAT D and SEASAT A, only if there is a receiving station in New Zealand. Such a receiving station would be able to receive real-time imagery from all LANDSAT and SEASAT satellites (this includes LANDSATS I and II). Coverage would no longer be limited by the storage capacity of the on-board tape recorder. Fig. 2.3 shows the area that would be covered by a receiving station in Wellington with a  $10^\circ$  or a  $20^\circ$  minimum angle of elevation. A minimum angle of elevation of  $10^\circ$  would give coverage of the whole of the proposed 200 mile exclusive economic zone around New Zealand's coasts.

LANDSAT C, which is due to be launched in late 1977 or early 1978, will carry all the equipment present on LANDSAT II. In addition it will have a fifth sensor MSS band 8 which will be sensitive to thermal emitted radiation and have a nominal filter passband from 10.4 to 12.6  $\mu\text{m}$ . The nominal instantaneous field of view of this sensor will be 237 m square. The along-row and column sampling distances in band 8 are three times those in the other MSS bands. This band should measure the average ground temperature within a pixel to an accuracy of  $1.5^\circ\text{C}$ .

A return beam vidicon (RBV) camera system will also be incorporated on LANDSAT C. This RBV two-camera system will take four 98 km square images which together will cover the area included in the corresponding MSS image. The RBV cameras will use single broad-band filters from 505 to 750 nm, and have a nominal instantaneous field of view of 40 m square. Data from the RBV will be recorded on the on-board tape recorder. We hope to receive RBV coverage of New Zealand.

LANDSAT D, to be launched in 1980 or 1981, is planned to carry a "thematic mapper" with six spectral bands instead of the five on LANDSAT C. These bands have been carefully chosen to give improved discrimination of agricultural targets. The pixel size for LANDSAT D will be 30 m square. It is possible that a multispectral scanner like that on LANDSAT C will be carried as well.

SEASAT A, planned for launch in May 1978, will carry a number of instruments. The most interesting from our point of view is the synthetic aperture imaging radar system for producing high-resolution images of the sea surface. Images over land will

also be taken. This single-band active, microwave imaging system will have a resolution of 25 m.

Two other satellites which would be of interest, if a receiving station were available in New Zealand, are Nimbus G and the Heat Capacity Mapping Mission (HCMM). Nimbus G carries a Coastal Zone Colour Scanner designed to detect coastal upwelling, and to map currents and fishing areas. HCMM carries a heat sensing, imaging radiometer with a ground resolution of about 500 m, and its orbit is designed to give day/night coverage over wide areas. This should enable the thermal capacity of surface rocks and soils and soil moisture content to be measured.

#### References

NASA (1976): "LANDSAT Data Users Handbook," Goddard Space Flight Center. Document No. 76SDS4258 September 1976.

Thomas, V. L., (1975): Generation and physical characteristics of the LANDSAT 1 and 2 MSS computer compatible tapes", Goddard Space Flight Center. Document No. X-563-75-223.

Heller, R. C. (1971): in "Remote Sensing," National Academy of Sciences, Washington, p. 35.

TABLE 2.1—LANDSAT I Scenes received

| PEL<br>Sequential<br>ID No. | Map<br>Index<br>No. | Location          | Scene ID<br>No. | GMT<br>Date<br>(YYMMDD) | PEL<br>70 mm<br>Ref | Cloud<br>Cover<br>Quality |
|-----------------------------|---------------------|-------------------|-----------------|-------------------------|---------------------|---------------------------|
| 0101                        | 76                  | Arthur's Pass     | 1502-21362      | 731207                  | 1/1                 | A                         |
| 0102                        | 77                  | Timaru            | 1502-21365      | 731207                  | 1/1,2               | A                         |
| 0103                        | 78                  | Dunedin           | 1502-21371      | 731207                  | 1/2                 | B                         |
| 0104                        | 86                  | Hokitika          | 1503-21421      | 731208                  | 1/3                 | A                         |
| 0105                        | 87                  | Mt. Cook          | 1503-21423      | 731208                  | 1/3,4               | A                         |
| 0106                        | 88                  | Central Otago     | 1503-21430      | 731208                  | 1/4                 | A                         |
| 0107                        | 54                  | Manawatu          | 1518-21235      | 731223                  | 1/5                 | A                         |
| 0108                        | 75                  | Nelson            | 1520-21354      | 731225                  | 1/5,6               | A                         |
| 0109                        | 108                 | Puysegur Pt.      | 1505-21542      | 731210                  | 1/6                 | A                         |
| 0110                        | 107                 | Te Anau           | 1505-21540      | 731210                  | 1/7                 | A                         |
| 0111                        | 74                  | Farewell Spit     | 1520-21351      | 731225                  | 1/7,8               | A                         |
| 0112                        | 98                  | Gore              | 1558-21470      | 740201                  | 1/8                 | A                         |
| 0113                        | 71                  | Hauraki Gulf      | 1556-21325      | 740130                  | 1/9                 | A                         |
| 0114                        | 90                  | Three Kings       | 1648-21420      | 740502                  | 1/9,10              | A                         |
| 0115                        | 72                  | Auckland          | 1556-21331      | 740130                  | 1/10                | A                         |
| 0116                        | 52                  | Bay of Plenty     | 1482-21233      | 731117                  |                     | C                         |
| 0117                        | 89                  | Sth of Owaka      | 1503-21432      | 731208                  |                     | B                         |
| 0118                        | 89+                 | SSE of Stewart Is | 1503-21435      | 731208                  |                     | C                         |
| 0119                        | 52                  | Whakatane         | 1518-21230      | 731223                  |                     | C                         |
| 0120                        | 53                  | Hawkes Bay        | 1518-21232      | 731223                  |                     | B                         |
| 0121                        | 65                  | Cook Str.         | 1519-21300      | 731224                  |                     | C                         |
| 0122                        | 71                  | Whangarei         | 1520-21340      | 731225                  |                     | C                         |
| 0123                        | 52                  | Bay of Plenty     | 1536-21223      | 740110                  |                     | B                         |
| 0124                        | 73                  | New Plymouth      | 1556-21334      | 740130                  |                     | A                         |
| 0125                        | 85                  | Westport          | 1575-21395      | 740218                  |                     | B                         |

Cloud Cover quality - A: Most of terrain cloud free

B: Some cloud over land but some information  
extractable

C: Mostly cloud

TABLE 2.2—LANDSAT II imagery received at PEL

| PEL<br>Sequen-<br>tial<br>No. | Map<br>Index<br>No. | Location      | Scene ID<br>No. | GMT<br>Date<br>(YYMMDD) | Cloud<br>Cover<br>(%) | MSS band<br>quality |   |   |   | PEL<br>70 mm<br>Ref |
|-------------------------------|---------------------|---------------|-----------------|-------------------------|-----------------------|---------------------|---|---|---|---------------------|
|                               |                     |               |                 |                         |                       | 4                   | 5 | 6 | 7 |                     |
| 01                            | 55                  | Cp. Palliser  | 2334-21132      | 751222                  | 10                    | 8                   | 5 | 5 | 5 | 2/4,3               |
| 02                            | 64                  | Wanganui      | 2299-21190      | 751117                  | 20                    | 5                   | 5 | 5 | 8 | 2/3                 |
| 03                            | 65                  | Cook Str.     | 2299-21192      | 751117                  | 30                    | 5                   | 5 | 5 | 2 | 2/2                 |
| 04                            | 87                  | Benmore       | 2265-21321      | 751014                  | 30                    | 5                   | 2 | 8 | 8 | 2/1                 |
| 05                            | 88                  | Dunedin       | 2265-21323      | 751014                  | 40                    | 5                   | 5 | 5 | 5 | 2/2,1               |
| 06                            | 62                  | Coromandel    | 2281-21182      | 751030                  | 10                    | 5                   | 5 | 5 | 5 | 2/11,12             |
| 07                            | 76                  | Darfield      | 2282-21254      | 751031                  | 20                    | 5                   | 5 | 5 | 8 | 2/5                 |
| 08                            | 63                  | Taupo         | 2281-21185      | 751030                  | 30                    | 5                   | 0 | 5 | 5 | 2/12                |
| 09                            | 66                  | Kaikoura      | 2335-21192      | 751223                  | 10                    | 5                   | 5 | 5 | 8 | 2/4                 |
| 10                            | 65                  | Cook Str.     | 2335-21190      | 751223                  | 10                    | 8                   | 5 | 8 | 5 | 2/6                 |
| 11                            | 64                  | Wanganui      | 2335-21183      | 751223                  | 30                    | 5                   | 8 | 8 | 8 | 2/5,6               |
| 12                            | 77                  | Timaru        | 2192-21272      | 750802                  | 10                    | 5                   | 8 | 8 | 5 | 2/7                 |
| 13                            | 76                  | Darfield      | 2192-21265      | 750802                  | 10                    | 5                   | 8 | 5 | 8 | 2/7,8               |
| 14                            | 74                  | Farewell Spit | 2264-21251      | 751013                  | 30                    | 5                   | 5 | 5 | 5 | 2/8                 |
| 15                            | 65                  | Cook Str.     | 2281-21194      | 751030                  | 40                    | 5                   | 5 | 5 | 0 | 2/9                 |
| 16                            | 71                  | Whangarei     | 2264-21235      | 751013                  | 50                    | 5                   | 5 | 5 | 5 | 2/9,10              |
| 17                            | 75                  | Nelson        | 2282-21252      | 751031                  | 40                    | 5                   | 5 | 5 | 8 | 2/10                |
| 18                            | 53                  | Kaingaroa     | 2334-21123      | 751222                  | 10                    | 8                   | 8 | 8 | 8 | 2/11                |
| 19                            | 74                  | Farewell Spit | 2390-21233      | 760216                  | 40                    | 8                   | 8 | 8 | 8 | 3/1                 |
| 20                            | 73                  | New Plymouth  | 2390-21231      | 760216                  | 40                    | 8                   | 8 | 8 | 8 | 3/1,2               |
| 21                            | 63                  | Taumarunui    | 2389-21172      | 760215                  | 30                    | 5                   | 8 | 8 | 8 | 2/13                |
| 22                            | 72                  | Auckland      | 2390-21224      | 760216                  | 30                    | 5                   | 5 | 8 | 8 | 2/13,14             |
| 23                            | 62                  | Coromandel    | 2389-21170      | 760215                  | 40                    | 5                   | 8 | 5 | 8 | 3/8                 |
| 24                            | 61                  | Gt. Bar. Is.  | 2389-21163      | 760215                  | 40                    | 5                   | 5 | 8 | 8 | 3/9                 |
| 25                            | 76                  | Darfield      | 2390-21242      | 760216                  | 40                    | 8                   | 8 | 8 | 8 | 3/2                 |
| 26                            | 75                  | Nelson        | 2390-21240      | 760216                  | 50                    | 8                   | 8 | 8 | 8 | 2/14                |
| 27                            | 88                  | Lawrence      | 2391-21305      | 760217                  | 30                    | 8                   | 5 | 5 | 8 | 3/5                 |
| 28                            | 86                  | Hokitika      | 2391-21300      | 760217                  | 30                    | 5                   | 5 | 5 | 5 | 3/4                 |
| 29                            | 82                  | W. Pukekohe   | 2391-21282      | 760217                  | 50                    | 5                   | 5 | 5 | 5 | 3/7,8               |
| 30                            | 81                  | Dargaville    | 2391-21280      | 760217                  | 30                    | 5                   | 8 | 8 | 8 | 3/6                 |

TABLE 2.2 (continued)

| PEL<br>Sequen-<br>tial<br>No. | Map<br>Index<br>No. | Location        | Scene ID<br>No. | GMT<br>Date<br>(YYMMDD) | Cloud<br>Cover<br>(%) | MSS band<br>quality |   |   |   | PEL<br>70 mm<br>Ref |
|-------------------------------|---------------------|-----------------|-----------------|-------------------------|-----------------------|---------------------|---|---|---|---------------------|
|                               |                     |                 |                 |                         |                       | 4                   | 5 | 6 | 7 |                     |
| 31                            | 80                  | Nth Cape        | 2391-21273      | 760217                  | 10                    | 5                   | 8 | 8 | 5 | 3/7                 |
| 32                            | 87                  | Otematata       | 2391-21303      | 760217                  | 40                    | 5                   | 5 | 5 | 5 | 3/3                 |
| 33                            | 85                  | Cp. Foulwind    | 2391-21294      | 760217                  | 50                    | 8                   | 5 | 5 | 8 | 3/3,4               |
| 34                            | 84                  | W. Cp. Farewell | 2391-21291      | 760217                  | 40                    | 5                   | 5 | 8 | 5 | 3/5,6               |
| 35                            | 52                  | White Is.       | 2388-21112      | 760214                  | 40                    | 5                   | 5 | 8 | 5 | 3/9,10              |
| 36                            | 65                  | Cook Str.       | 2407-21174      | 760304                  | 50                    | 8                   | 5 | 8 | 8 | 3/11                |
| 37                            | 66                  | Kaikoura        | 2407-21181      | 760304                  | 50                    | 5                   | 8 | 8 | 8 | 3/11,1              |
| 38                            | 86                  | Hokitika        | 2409-21293      | 760306                  | 30                    | 8                   | 8 | 8 | 8 | 3/10                |
| 39                            | 43                  | Gisborne        | 2495-21025      | 760531                  | 10                    | 8                   | 5 | 8 | 8 | 3/12                |
| 40                            | 87                  | Benmore         | 2787-21172      | 770319                  | 30                    | 8                   | 8 | 8 | 8 | 3/13                |
| 41                            | 87                  | Benmore         | 2805-21163      | 770406                  | 0                     | 9                   | 9 | 9 | 9 | 3/13,1              |
| 42                            | 88                  | Dunedin         | 2805-21165      | 770406                  | 25                    | 9                   | 9 | 9 | 9 | 3/14                |
| 43                            | 97                  | Aspiring        | 2824-21211      | 770425                  | 30                    | 8                   | 8 | 8 | 8 | 3/15                |
| 44                            | 98                  | Lumsden         | 2824-21214      | 770425                  | 30                    | 8                   | 8 | 8 | 8 | 3/15,1              |

TABLE 2.3—CCT products available through PEL at 1 September 1977

| PEL<br>Sequential<br>ID No. | Map<br>Index<br>No. | Location           | Scene ID<br>No. | GMT<br>Date | Received=R<br>Ordered=<br>blank |
|-----------------------------|---------------------|--------------------|-----------------|-------------|---------------------------------|
| 0901                        | Antarctica          | McMurdo            | 1174-19433      | 730113      | R                               |
| 0101                        | 76                  | Canterbury         | 1502-21362      | 731207      | R                               |
| 0104                        | 96                  | Hokitika           | 1503-21421      | 731208      | R                               |
| 0105                        | 86                  | Mt. Cook           | 1503-21423      | 731208      | R                               |
| 0106                        | 88                  | Central Otago      | 1503-21430      | 731208      | R                               |
| 0107                        | 54                  | Manawatu           | 1518-21235      | 731223      | R                               |
| 0115                        | 72                  | Auckland           | 1556-21331      | 740130      | R                               |
| 0013                        | 76                  | Canterbury         | 2192-21265      | 750802      | R                               |
| 0012                        | 77                  | Timaru             | 2192-21272      | 750802      | R                               |
| 0004                        | 87                  | Benmore            | 2265-21321      | 751014      | R                               |
| 0005                        | 88                  | Dunedin            | 2265-21323      | 751014      | R                               |
| 0006                        | 62                  | Coromandel         | 2281-21182      | 751030      | R                               |
| 0008                        | 63                  | Taupo              | 2281-21185      | 751030      | R                               |
| 0015                        | 65                  | Blenheim           | 2281-21194      | 751030      | R                               |
| 0017                        | 75                  | Nelson             | 2282-21252      | 751031      | R                               |
| 0007                        | 76                  | Canterbury         | 2282-21254      | 751031      | R                               |
| 0002                        | 64                  | Wanganui           | 2299-21190      | 751117      | R                               |
| 0018                        | 53                  | Kaingoroa          | 2334-21123      | 751222      | R                               |
| 0001                        | 55                  | Cape Palliser      | 2334-21132      | 751222      | R                               |
| 0010                        | 65                  | Blenheim           | 2335-21190      | 751223      | R                               |
| 0024                        | 61                  | Gt. Bar. Is.       | 2389-21163      | 760215      | R                               |
| 0023                        | 62                  | Coromandel         | 2389-21170      | 760215      | R                               |
| 0021                        | 63                  | Taumarunui         | 2389-21172      | 760215      | R                               |
| 0020                        | 73                  | New Plymouth       | 2390-21231      | 760216      | R                               |
| 0022                        | 72                  | Auckland           | 2390-21224      | 760216      | R                               |
| 0026                        | 75                  | Nelson             | 2390-21240      | 760216      | R                               |
| 0031                        | 90                  | Nth. Cape          | 2391-21273      | 760217      | R                               |
| 0034                        | 84                  | W. of Cp. Farewell | 2391-21291      | 760217      | R                               |
| 0039                        | 43                  | Gisborne           | 2495-21025      | 760531      | R                               |
| 0040                        | 87                  | Benmore            | 2787-21172      | 770319      | R                               |
| 0041                        | 87                  | Benmore            | 2805-21163      | 770406      | R                               |
| 0042                        | 88                  | Dunedin            | 2805-21165      | 770406      | R                               |
| 0043                        | 97                  | Aspiring           | 2824-21211      | 770425      |                                 |
| 0044                        | 98                  | Lumsden            | 2824-21214      | 770425      |                                 |

TABLE 2.3— (continued)

| PEL<br>Sequential<br>ID No. | Map<br>Index<br>No. | Location      | Scene ID<br>No. | GMT<br>Date | Received=R<br>Ordered =<br>blank |
|-----------------------------|---------------------|---------------|-----------------|-------------|----------------------------------|
| 102                         | 77                  | Timaru        | 1502-21365      | 731207      |                                  |
| 103                         | 78                  | Dunedin       | 1502-21371      | 731207      |                                  |
| 107                         | 54                  | Manawatu      | 1518-21235      | 731223      |                                  |
| 108                         | 75                  | Nelson        | 1520-21354      | 731225      |                                  |
| 109                         | 108                 | Puysegur Pt.  | 1505-21542      | 731210      |                                  |
| 110                         | 107                 | Te Anau       | 1505-21540      | 731210      |                                  |
| 111                         | 74                  | Farewell Spit | 1520-21351      | 731225      |                                  |
| 112                         | 98                  | Gore          | 1558-21470      | 740201      |                                  |
| 113                         | 71                  | Hauraki Gulf  | 1556-21325      | 740130      |                                  |
| 114                         | 90                  | Three Kings   | 1648-21420      | 740502      |                                  |
| 123                         | 52                  | Bay of Plenty | 1536-21223      | 740110      |                                  |
| 124                         | 73                  | New Plymouth  | 1556-21334      | 740130      |                                  |



TABLE 2.4—Multispectral surveys flown using the PEL Hasselblad camera system

| Survey number | GMT date | Area                | Survey purpose   |
|---------------|----------|---------------------|------------------|
| MSH1          | 5.74     | Tasman Glacier      | snow study       |
| MSH2          | 7.74     | Ruatoria/Tolaga Bay | soil survey      |
| MSH3          | 4. 4.75  | Darfield            | agriculture      |
| MSH4          | 2. 8.75  | "                   | "                |
| MSH5          | 13.11.75 | "                   | "                |
| MSH6          | 18. 2.76 | "                   | "                |
| MSH6T         | 18. 2.76 | Torlesse            | catchment survey |
| MSH7          | 14. 5.76 | Kaingaroa           | forest survey    |
| MSH7T         | 14. 5.76 | Napier              | test             |
| MSH8          | 19. 2.76 | Kowai catchment     | catchment survey |
| MSH8T         | 24. 2.76 | - -                 | - -              |
| MSH9          | 4. 2.77  | Darfield            | agriculture      |
| MSH10         | 4. 2.77  | Leeston             | "                |
| MSH11         | 4. 2.77  | Eyrewell            | forest survey    |
| MSH12         | 4. 2.77  | Hammer              | " "              |
| MSH13         | 15.12.76 | Tauranga            | test             |
| MSH14         | 9. 2.77  | Pauatahanui         | harbour survey   |
| MSH15         | 7. 4.77  | Ruahine             | catchment study  |

TABLE 2.5—Achievable photographic and ground resolution for various scales and AGL heights for the operational PEL Hasselblad multispectral camera system

| Scale    | Flying Height<br>AGL (ft) | System Resolution<br>(lp/mm) | Achievable<br>ground<br>resolution<br>(ft) |
|----------|---------------------------|------------------------------|--------------------------------------------|
| 1:63,360 | 20,790                    | 19                           | 10.9                                       |
| 1:50,000 | 16,400                    | 19                           | 8.6                                        |
| 1:40,000 | 13,125                    | 18                           | 7.3                                        |
| 1:25,000 | 8,200                     | 17                           | 4.8                                        |
| 1:20,000 | 6,560                     | 17                           | 3.9                                        |
| 1:15,000 | 4,920                     | 16                           | 3.1                                        |
| 1:10,000 | 3,280                     | 15                           | 2.2                                        |
| 1:7,500  | 2,460                     | 14                           | 1.8                                        |
| 1:5,000  | 1,640                     | 12                           | 1.4                                        |
| 1:3,000  | 985                       | 9                            | 1.1                                        |
| 1:2,500  | 820                       | 8                            | 1.0                                        |

For the PEL operational case:

$$f = 100 \text{ mm}, \quad v = 100 \text{ m.p.h.}, \quad t = \frac{1}{250} \text{ sec.}, \quad R_f = 40 \text{ lp/mm},$$

$$R_1 = 40 \text{ lp/mm}, \quad R_i \text{ from equation (2.3)}$$

TABLE 2.6—Corresponding ground area and image side length of PEL Hasselblad imagery as a function of survey scale

| Survey Scale | Image side length (mile) | area covered (sq. mile) |
|--------------|--------------------------|-------------------------|
| 1:63,360     | 2.126                    | 4.52                    |
| 1:50,000     | 1.678                    | 2.82                    |
| 1:40,000     | 1.342                    | 1.80                    |
| 1:25,000     | 0.839                    | $7.0 \times 10^{-1}$    |
| 1:20,000     | 0.671                    | $4.5 \times 10^{-1}$    |
| 1:15,000     | 0.503                    | $2.5 \times 10^{-1}$    |
| 1:10,000     | 0.336                    | $1.1 \times 10^{-1}$    |
| 1:7,500      | 0.252                    | $6.4 \times 10^{-2}$    |
| 1:5,000      | 0.168                    | $2.8 \times 10^{-2}$    |
| 1:3,000      | 0.101                    | $1.0 \times 10^{-2}$    |
| 1:2,500      | 0.084                    | $7.1 \times 10^{-3}$    |

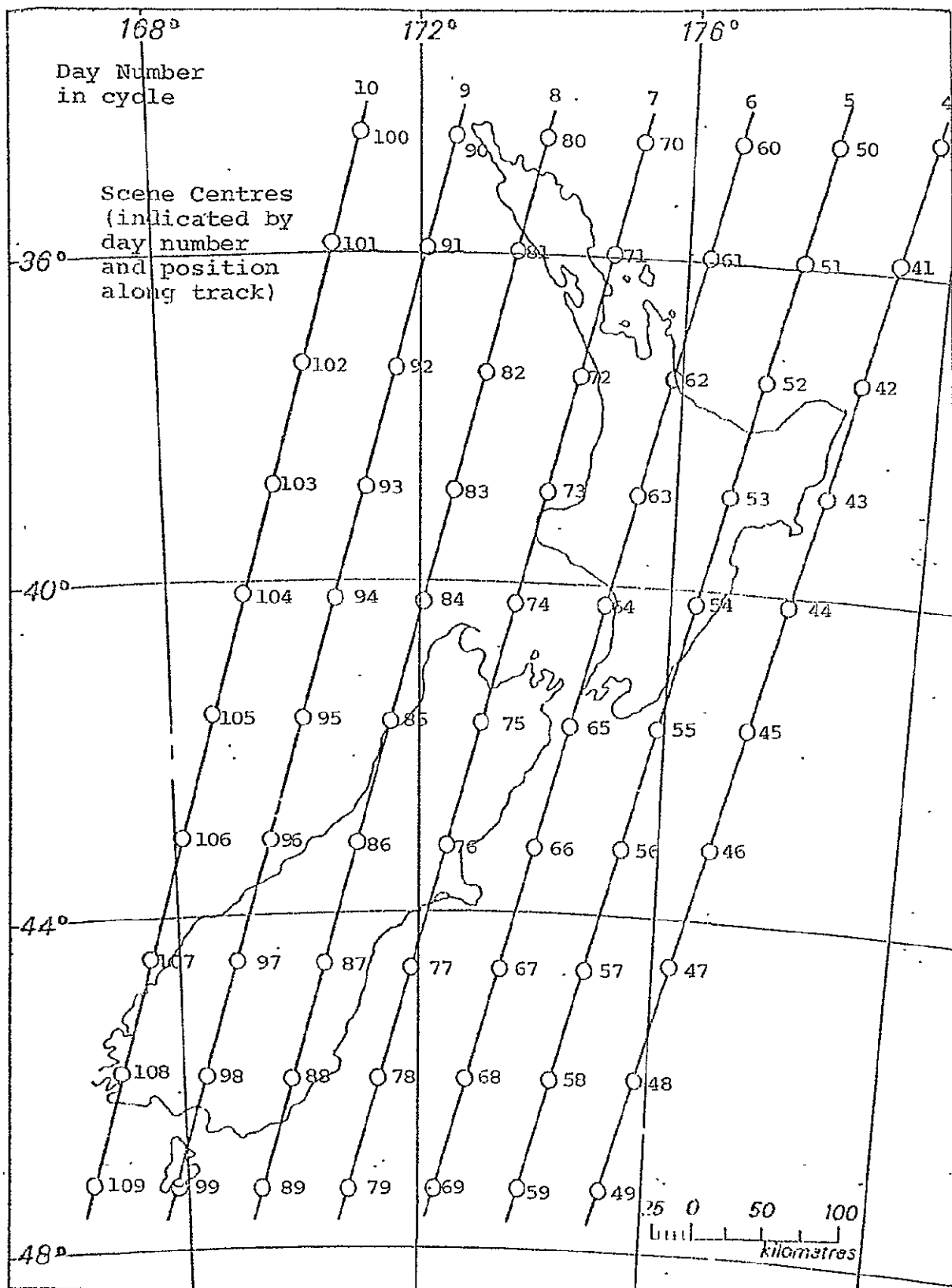
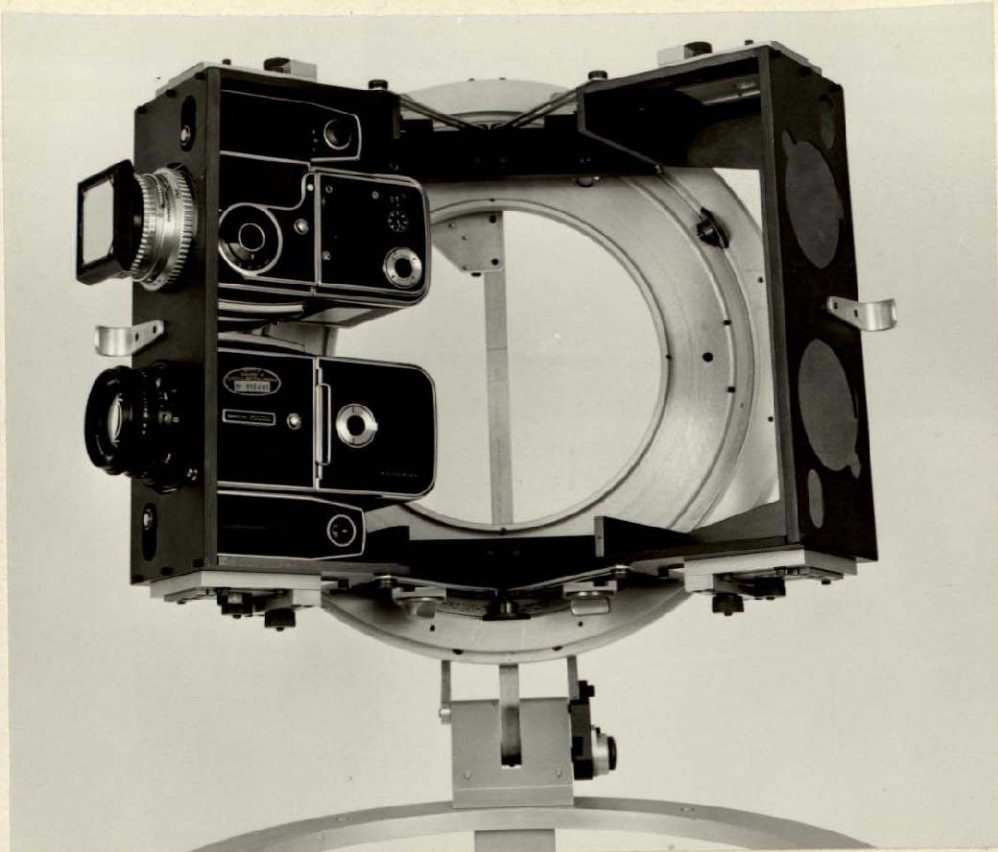


Fig. 2.1—LANDSAT 2 ORBITAL TRACK AND SCENE CENTRE LOCATIONS



ORIGINAL PAGE IS  
OF POOR QUALITY

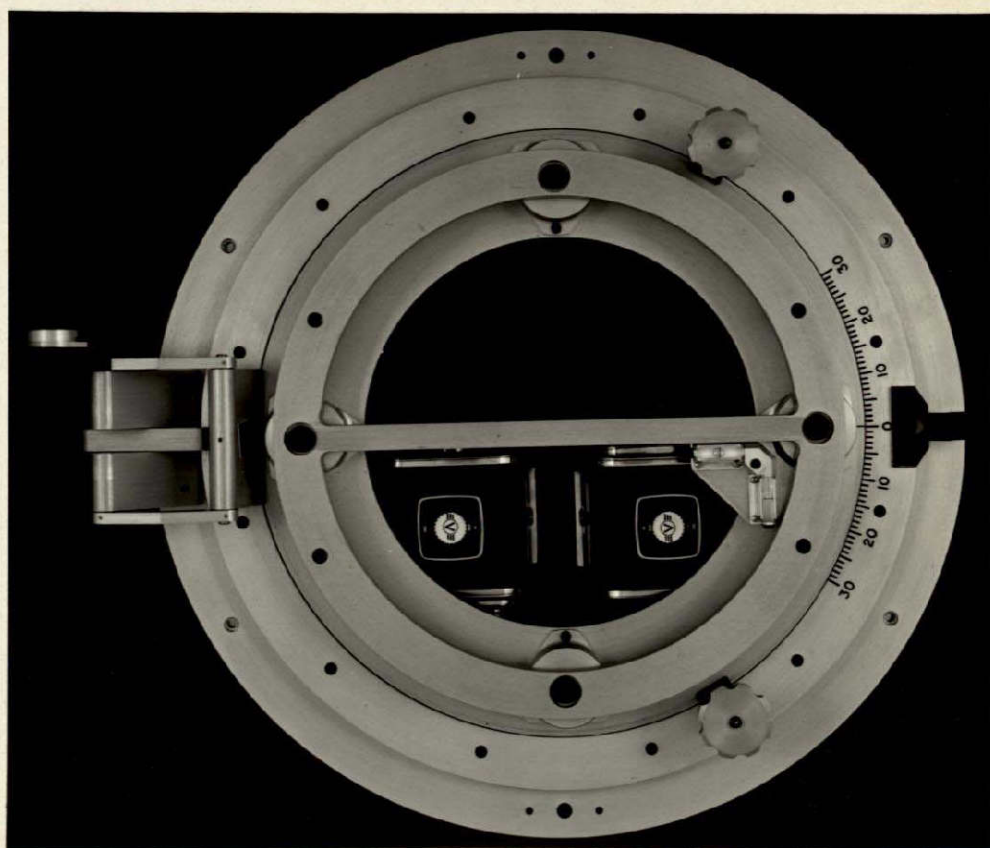


Fig. 2.2 Aircraft multispectral camera system.

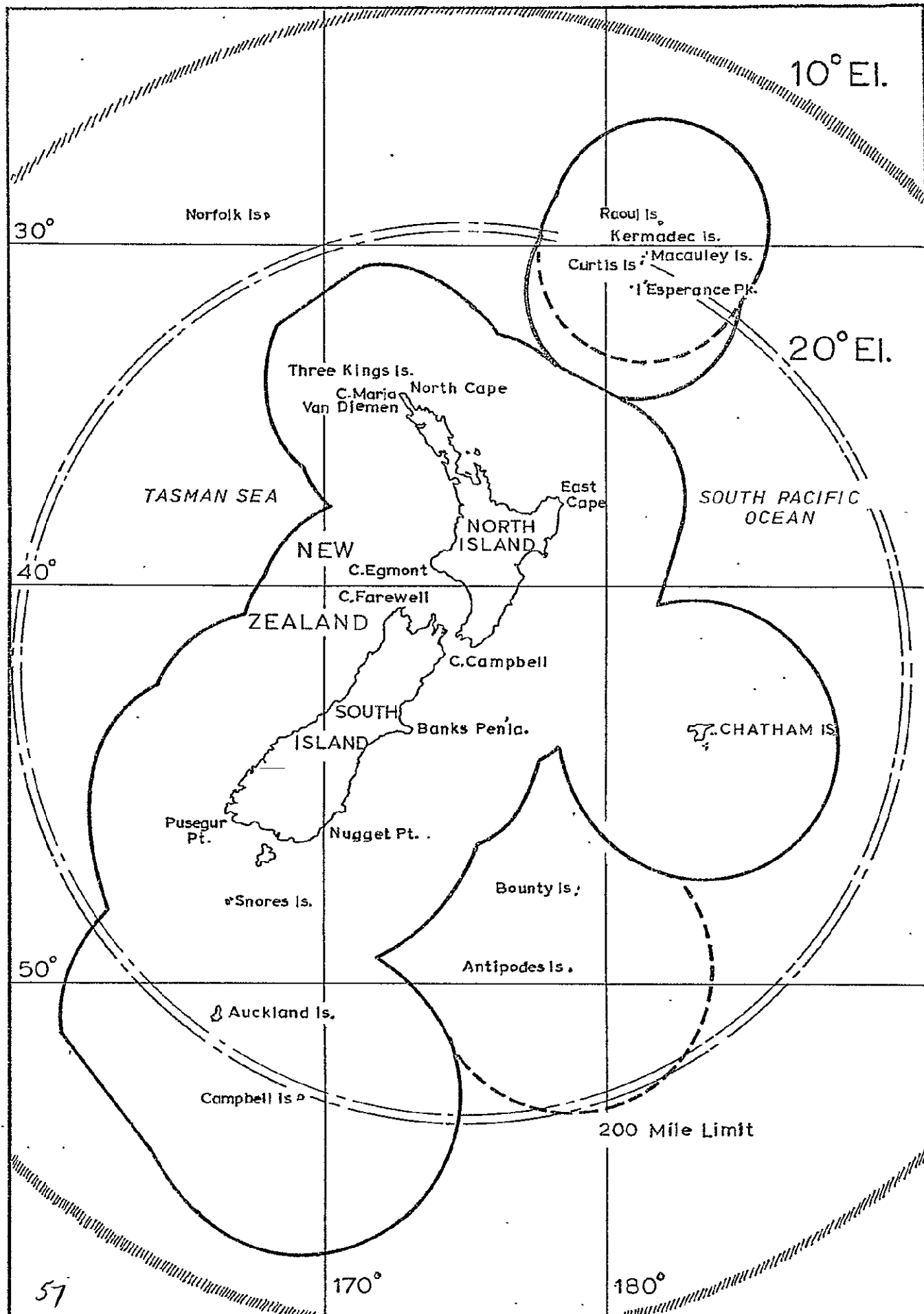


Diagram illustrating the 200 mile economic zone including aerial coverage possible from a Wellington receiving station with a satellite altitude of 700 km. Antenna elevations of 10° and 20° are portrayed.

FIG. 2-3

## CHAPTER 3

## LANDSAT RADIOMETRY

## 3.1 The Measurement of Target Radiance

P. J. Ellis, A. D. Fowler

ABSTRACT

One of the fundamental problems in radiometry is caused by the non ideal spectral responsivity of the radiometers. For a target of unknown spectral radiance, this introduces errors into the radiance measurements which cannot be accurately estimated. Measurements from radiometers which, for instance, utilise the LANDSAT MSS spectral band cannot be reliably compared unless their spectral responsivities are almost identical, and this is also true for the comparison of band ratios.

We have measured the spectral responsivities of 3 MSS type radiometers in the laboratory. These, together with the known spectral responsivities of the LANDSAT II MSS, have been used in a computer simulation to predict the differences in instrument reading which would occur when viewing 3 "standard" targets of differing spectral radiance. It is shown that errors can often be reduced if the instrument spectral responsivity curve is symmetrical in form.



### 3.1.1 INTRODUCTION

A scene from the LANDSAT Multi-Spectral Scanner (MSS) is first viewed by the user as a set of monochrome pictures, or as a colour composite. However, increasing use is being made of the digital data from which these pictures are derived, and which are generally available as a set of numbers stored on a computer compatible tape (CCT). Each number is related to the radiance of a single picture element (pixel) within one of the four MSS spectral bands.

A direct consequence of the LANDSAT project is that radiometers utilising the MSS band passes are now employed in ground truth measurements and aircraft underflights.

This first paper (3.1) is concerned with the difficulties of comparing radiance readings obtained from different instruments, and in defining these measurements in terms of absolute values. This fundamental problem of radiometry occurs when the target spectral radiance varies unpredictably within the band-pass of the measuring instrument, causing errors which are hard to estimate. Nicodemus (1973) and other authors have investigated this subject in detail, and it is our purpose to introduce additional criteria which may reduce these errors. We demonstrate the possible magnitude of these errors in a practical situation by using the known spectral responsivities of laboratory radiometers, and the LANDSAT II MSS, in a computer-simulated experiment involving three "targets" of different spectral radiance.

We believe that the concepts discussed here are of particular importance to users of remote sensing data, and are not always fully appreciated. These concepts are therefore reviewed in some detail. Terms and definitions used in radiometry can still be a subject of controversy, and those found in the text are defined in the appendix. The definitions are in accordance with those of the CIE and IEC (1970) and re-stated by Nicodemus (1976).

Part 2 of this chapter compares radiance measurements made by the LANDSAT II MSS of a single ground target, with similar measurements from our aircraft radiometer, of the same target near the time of the LANDSAT overflight.

### 3.1.2 A REVIEW OF RADIANCE MEASUREMENT PRINCIPLES

The output of a radiometer will depend on the radiance of all objects within its field of view. In the case of an imaging instrument such as the LANDSAT MSS, it is the instantaneous field of view (IFOV) which determines the output, and for the MSS this represents an area of approximately 80 m square on the ground. In this paper, we assume that in all cases the output is linearly related to target radiance averaged over the field of view. Modern radiometers closely conform to this approximation. The arguments presented here are concerned only with the spectral characteristics of instrument and target, and the way in which these characteristics affect the accuracy of the measurement.

Many radiometers can be adapted to read the incident power on a surface, e.g., irradiance, and our arguments apply equally well to instruments operating in this mode.

A radiometer can be considered to fall into one of three categories, "wideband", "narrow-band", or "intermediate-band". Each category will respond differently to a given target, and we begin by considering each of these in turn.

### 3.1.2.1 Wide-Band Radiometer

Fig. 3.1 shows a "wide-band" radiometer with a "spectrally flat" characteristic, viewing a target of spectral radiance  $L(\lambda)$  whose radiant output is confined between the limits  $\lambda_1$  and  $\lambda_2$ . The spectral radiance responsivity  $R_L(\lambda)$  of the instrument is constant between those limits.

The instrument reading  $S$  is equal to the product  $L(\lambda) \cdot R_L(\lambda)$ , integrated over all wavelengths. Thus if  $R_L(\lambda)$  (constant) is known, then:

$$L = S/R_L \text{ [W.cm}^{-2}\text{.sr}^{-1}] \quad \dots 3.1$$

where  $L$  is the target radiance between the "natural" limits  $\lambda_1$  and  $\lambda_2$ .

This instrument will correctly indicate the radiance of any target whose spectral radiance does not extend beyond  $R_L(\lambda)$  (constant). Measurements made with "spectrally flat" instruments can be intercompared with accuracy, although such measurements convey little information about the spectral distribution of the target radiance.

### 3.1.2.2 Narrow-Band Radiometer

In this category, the instrument bandwidth is narrow enough to allow the assumption that the target has a constant spectral radiance over the instrument bandpass. If we determine the average spectral radiance responsivity  $R_L(\Delta\lambda)$ , then the target radiance between the limits  $\lambda_1$  and  $\lambda_2$  is given by:

$$L_{\lambda_1}^{\lambda_2} = S/R_L(\Delta\lambda) \text{ [W.cm}^{-2}\text{.sr}^{-1}] \quad \dots 3.2$$

This situation is shown in Fig. 3.2. Again, the radiance of any target which satisfies this condition will be correctly measured, between the specified limits. Comparisons can therefore be made of measurements by different instruments operating in this category, which usually includes, for instance, wavelength scanning instruments such as the spectrometer.

Note the "duality" of these two categories 3.1.2.1 and 3.1.2.2, which represent the extreme situations.

### 3.1.2.3 Intermediate-Band Radiometer

It is the "intermediate" situation which raises the problem that may occur in, for instance, LANDSAT radiometry. Fig. 3.3 shows an "intermediate" bandwidth radiometer viewing a target

whose spectral radiance varies within the instrument bandwidth.

If the target spectral radiance  $L(\lambda)$  is known, it is possible to compute the target radiance between the limits  $\lambda_1$  and  $\lambda_2$ . A "calibration" radiance responsivity  $R$  can be derived such that:

$$L_{\lambda_1}^{\lambda_2} = S/R \text{ [W.cm}^{-2}\text{.sr}^{-1}] \dots 3.3.$$

However, this value of  $R$  will only give a correct radiance reading for targets with the same relative spectral radiance, that is, for a spectral distribution of the same shape as  $L(\lambda)$ . Consider the case of a second instrument, whose spectral radiance responsivity differs only in shape from  $R_L(\lambda)$  (Fig. 3.3). This instrument may also be calibrated to read  $L_{\lambda_1}^{\lambda_2}$  correctly, but when both instruments view another target with a different spectral radiance, their outputs will not agree, and in general neither instrument will correctly indicate the true radiance between  $\lambda_1$  and  $\lambda_2$ .

There are thus two problems. The first is the error in the relative outputs of two instruments of different spectral responsivity when viewing a target whose spectral radiance is different from that of the "calibration" target. These errors extend to "band-ratios" measured by, for instance, different MSS band radiometers. The second problem is the inability to read correctly the radiance of an "unknown" target within specified limits  $\lambda_1$  and  $\lambda_2$ . These problems are among the most fundamental in radiometry, and are not always appreciated by users of remote sensing data. In section 3.1.5 the practical consequences of differing spectral radiance responsivities in the LANDSAT MSS and in laboratory instruments are shown.

#### 3.1.2.4 Factors which Influence Spectral Responsivity

The spectral responsivity of a radiometer is a function of all the optical components including the detector. Of these, the bandpass filter usually has the dominant influence. In the visible and near infrared spectral region, bandpass filters are of two general types, absorption filters and dielectric multilayer filters. Multilayer filters are superior to the absorption type in that the "cut on" and "cut off" edges which define the bandpass can be much steeper, with more effective "blocking" outside the bandpass region. Careful manufacture can also produce more precise "pitching" of the bandpass than is possible with the absorption filter.

Even so, dielectric multilayer filters vary considerably in spectral transmittance due to manufacturing tolerances. In the MSS bands, these tolerance variations are clearly seen in Figs 3.7, 3.8, 3.9, and 3.10, which show the relative spectral responsivities of the LANDSAT MSS and laboratory radiometers.

#### 3.1.3 CALIBRATION AND NORMALISATION

A "bandpass" radiometer is usually required to measure target radiance within certain "nominal" wavelengths. The ideal

instrument would have a spectral responsivity of constant high value within these wavelengths and zero outside of them. In practice, the situations of Figs 3.7-3.10 are more likely to be true, and the problem is to calibrate each band to give the most accurate readings for targets of any spectral radiance distribution. This calibration process applied to spectrally selective instruments is termed normalisation and is considered in detail by Nicodemus (1973) and Eberhardt (1968). Nicodemus extends this concept to cover non-uniform responsivity with respect to other radiation parameters. Here, we consider only normalisation with respect to wavelength.

Two quantities are needed to calibrate a radiometer. One is the (constant) radiance responsivity which is used to relate the output signal  $S$  to the target radiance  $L$ . The other is the bandpass, that is, the spectral region within which target radiance is being measured. This "nominal" bandpass need not necessarily coincide with the bandpass over which the instrument responsivity is non-zero.

It is possible to choose one of a whole range of "normalised" responsivities, and for each choice there is an appropriate bandpass which minimises the error in an absolute radiance measurement. Conversely, for each "nominal" bandpass there is a radiance responsivity which fulfils the same condition.

We illustrate this concept by considering two common types of normalisation and then the more general case.

### 3.1.3.1 Peak Normalisation

Fig. 3.4 shows a situation in which the peak spectral radiance responsivity is  $R_L(\lambda_m)$ . If we use  $R_L(\lambda_m)$  as the "calibration" responsivity, then:

$$L_{np} = S/R_L(\lambda_m) \text{ [W.cm}^{-2}\text{.sr}^{-1}] \quad \dots \quad 3.4$$

where  $L_{np}$  is the peak normalised target radiance.

The instrument responds to radiation between the wavelengths  $\lambda_1$  and  $\lambda_2$  and the target radiance between these wavelengths is:

$$L_{\lambda_1}^{\lambda_2} = \int_{\lambda_1}^{\lambda_2} L(\lambda) \cdot d\lambda \text{ [W.cm}^{-2}\text{.sr}^{-1}] \quad \dots \quad 3.5$$

$L_{np}$  is always less than, or at best equal to  $L_{\lambda_1}^{\lambda_2}$ . In fact  $L_{np}$  is the radiance of a "monochromatic" target whose output is concentrated at the wavelength  $\lambda_m$ .  $L_{np}$  thus gives only the lower limit to the real value of  $L_{\lambda_1}^{\lambda_2}$ , and in practice large differences can exist between these two values.

A more accurate result is obtained if the measurement bandpass is assumed to be the "peak normalised bandpass". In Fig. 3.4 (b) the wavelengths  $\lambda_A$  and  $\lambda_B$  are the boundaries of an "equivalent square" bandpass of height  $R_L(\lambda_m)$  and area equal to the area under the spectral radiance responsivity curve.

For a target which is spectrally flat between  $\lambda_1$  and  $\lambda_2$ , the instrument output will correctly indicate target radiance between  $\lambda_A$  and  $\lambda_B$ . However, if the target spectral radiance varies between  $\lambda_1$  and  $\lambda_2$ , the output will contain errors whose magnitudes depend on the shape of  $L(\lambda)$ . Nicodemus (1973) treats this "bandwidth normalisation" as a separate case from peak normalisation of responsivity. We prefer to consider the two cases as part of the same calibration procedure, since they would generally be used together.

### 3.1.3.2 Average Normalisation

We assume in this case that the instrument is measuring radiance between its "natural" wavelength limits ( $\lambda_1$  and  $\lambda_2$  in Fig. 3.4). The appropriate "calibration" responsivity is then the average value of  $R_L(\lambda)$ , giving a correct output when viewing a spectrally flat target. As before, if the target spectral radiance varies between  $\lambda_1$  and  $\lambda_2$ , errors will occur.

### 3.1.3.3 Arbitrary Normalisation

It is possible to specify any arbitrary bandpass, preferably close to that of the instrument itself, and to find a normalising responsivity which causes the instrument to read correctly the target radiance within that bandpass. If the instrument is calibrated against a "spectrally flat" target, then it will give a correct reading for other targets only if they also are spectrally flat. Alternatively, if the calibration target is, for instance, a standard lamp of known but varying spectral radiance, then the instrument will correctly read the radiance of all targets with the same relative spectral distribution.

### 3.1.4 SYMMETRY OF THE RESPONSIVITY FUNCTION $R_L(\lambda)$

Generally, "intermediate" bandpass instruments have spectral responsivities which differ markedly from the ideal "square" characteristics (Figs 3.7-3.10). Two cases of non-ideal spectral responsivities are worth considering. In the first case, the characteristic is symmetrical about a centre wavelength  $\lambda_c$  (Fig. 3.5). In the second case, it is asymmetric about  $\lambda_c$ . For the purpose of our analysis we use a simplified target spectral radiance, which is a straight line of arbitrary slope over the instrument bandpass (Fig. 3.5(a)). In many practical cases, this condition is approximately true and becomes more probable as the instrument bandwidth is decreased.

#### 3.1.4.1 The Symmetrical Case

Returning to Fig. 3.5, we see that target spectral radiance is given by:

$$L(\lambda) = M \cdot \Delta\lambda + N \text{ [W.cm}^{-2}\text{.sr}^{-1}\text{.nm}^{-1}] \quad \dots \quad 3.6$$

where  $\Delta\lambda$  is  $(\lambda - \lambda_c)$

The instrument output is thus:

$$S = \int_{-\Delta\lambda_A}^{\Delta\lambda_A} (M \cdot \Delta\lambda + N) \cdot R_L(\Delta\lambda) \cdot d\Delta\lambda \quad [S] \quad \dots \quad 3.7$$

Because of the symmetry of  $R_L(\Delta\lambda)$  about  $\lambda_c$ :

$$R_L(\Delta\lambda) = R_L(-\Delta\lambda)$$

Now the integral of  $S(\lambda)$  between limits  $\lambda_c$  and  $(\lambda_c + \Delta\lambda_A)$

$$S_1 = \int_0^{\Delta\lambda} (M \cdot \Delta\lambda + N) \cdot R_L(\Delta\lambda) \cdot d\lambda$$

and between limits  $(\lambda_c - \Delta\lambda_A)$  and  $\lambda_c$ :

$$S_2 = \int_{-\Delta\lambda_A}^0 (M \cdot \Delta\lambda + N) \cdot R_L(\Delta\lambda) \cdot d\Delta\lambda \quad \dots \quad 3.8$$

The integral  $S_2$  does not change if  $L(\lambda)$  and  $R(\lambda)$  are "folded" about  $\lambda_c$ , to lie between  $\lambda_c$  and  $(\lambda_c + \Delta\lambda_A)$ . Then  $R_L(\Delta\lambda)$  and  $N$  retain their values and slope  $M$  is reversed.

Thus:

$$S_2 = \int_0^{\Delta\lambda_A} (-M \cdot \Delta\lambda + N) \cdot R_L(\Delta\lambda) \cdot d\Delta\lambda$$

$$\text{and } S_1 + S_2 = S = \int_0^{\Delta\lambda_A} 2 \cdot N \cdot R_L(\Delta\lambda) \cdot d\Delta\lambda \quad [S] \quad \dots \quad 3.9$$

The absence of  $M$  in 3.9 indicates that an instrument which has been calibrated against a "spectrally flat" or "constant slope" target will correctly indicate the radiance of all targets with any degree of "constant slope" over the instrument bandpass. This proof can be extended to cover any target whose spectral radiance is not a straight line, but is antisymmetric about the wavelength  $\lambda_c$ .

#### 3.1.4.2 The Asymmetrical Case

If we replace the symmetrical spectral radiance responsivity of Fig. 3.5(b) by any curve which is asymmetrical about  $\lambda_c$ , then:

$$R_L(\Delta\lambda) \neq R_L(-\Delta\lambda)$$

in which case 3.8 becomes:

$$S_2 = \int_{-\Delta\lambda_A}^0 (M \cdot \Delta\lambda + N) \cdot R_L(-\Delta\lambda) \cdot d\Delta\lambda$$

The terms containing  $M$  do not cancel when  $S_1$  and  $S_2$  are added. Therefore this instrument calibrated against a "spectrally flat" target will not correctly read the radiance of a "non-flat" target. The degree of error will depend on the magnitude of the target "slope" and the degree of asymmetry of  $R_L(\lambda)$ .

If the shape of the asymmetric responsivity curve is known, it is possible to predict the errors which may occur for a given target. We assume that the curve  $R_L(\lambda)$  can be approximated by a polynomial function between the limits  $(\lambda_c - \Delta\lambda_A)$  and  $(\lambda_c + \Delta\lambda_A)$ .

Then:

$$R_L(\Delta\lambda) = R_L(\lambda_m) \cdot (a_0 + (a_1 \cdot \beta) + (a_2 \cdot \beta^2) + (a_3 \cdot \beta^3) + \dots) \dots 3.10$$

where  $\beta = \Delta\lambda / \Delta\lambda_A$

Then:

$$\begin{aligned} S &= \int_{-1}^1 (M \cdot \Delta\lambda_A \beta + N) \cdot R_L(\lambda_m) \cdot (a_0 + (a_1 \cdot \beta) + (a_2 \cdot \beta^2) + (a_3 \cdot \beta^3) + \dots) \cdot d\beta \\ &= M \cdot \Delta\lambda_A \cdot R_L(\lambda_m) \cdot \left[ \frac{a_0 \cdot \beta^2}{2} + \frac{a_1 \cdot \beta^3}{3} + \frac{a_2 \cdot \beta^4}{4} + \dots \right]_{-1}^1 \\ &\quad + N \cdot R_L(\lambda_m) \cdot \left[ a_0 \cdot \beta + a_1 \cdot \beta^2 + a_2 \cdot \beta^3 + \dots \right]_{-1}^1 \\ S &= 2 \cdot M \cdot \Delta\lambda_A \cdot R_L(\lambda_m) \cdot \left[ \frac{a_1}{3} + \frac{a_3}{5} + \dots \right] \\ &\quad + 2 \cdot N \cdot R_L(\lambda_m) \cdot \left[ \frac{a_0}{3} + \frac{a_2}{5} + \frac{a_4}{7} + \dots \right] \dots 3.11 \end{aligned}$$

The first term in 3.11 is the "asymmetry" component of S, and the second term is the symmetrical component. The ratio of the quantities in brackets gives an indication of the degree of asymmetry and of the output errors which might arise.

### 3.1.5 PREDICTED ERRORS WITH REAL INSTRUMENTS

We have used the concept of a "constant slope" target to predict the errors in radiance measurement which can exist with real instruments. This has been achieved by simulating three "standard" constant slope targets in the computer, and calculating the output for each target, of four instruments whose spectral responsivities have been measured. Each instrument is a four-band MSS radiometer. The first is the 24 detectors of the LANDSAT II MSS. The others are: a "Gamma Scientific" ground truth radiometer, and aircraft MSS radiometer developed at DSIR, and an "Exotech" radiometer operated by CSIRO, Australia.

Of the standard targets; target (1) is used as the calibration target and is spectrally flat over all the MSS bands. Target (2) has a spectral radiance consisting of a series of "positive slopes" extending from zero to two over each MSS band. Target (3)



has a spectral radiance of the same type as (2) but with "negative slope" (see Fig. 3.6).

To each of these targets, an instrument with a symmetrical spectral responsivity curve will give the same output.

The computed outputs, calibrated to read unity for target (1), are shown in Table 3.1. Table 3.2 lists the band ratios of bands 4/7 and 5/7 as an example of the different relative results that can be obtained when using different instruments. The relative spectral responsivities of the four 'A' detectors in the LANDSAT MSS and of the other instruments are shown in Figs 3.7, 3.8, 3.9, and 3.10.

As expected, the greatest measurement error occurs in the bands with the greatest asymmetry, notably in MSS band 7. Although the match between individual detectors is good in each band of the LANDSAT MSS, difficulties obviously arise when trying to compare spectral signatures derived from the different instruments.

In a real situation, for instance when viewing vegetation in the sharp transition region between low and high reflectance (at about 700 nm), the discrepancies can be much greater than are indicated in these tables.

### 3.1.6 METHODS OF REDUCING ERRORS

To improve measurement accuracy and to enable comparisons of spectral signatures to be made, an obvious course is to reduce the bandwidth of the radiometer. This should bring the target spectral radiance closer to the "constant slope" condition, within this reduced band. In practice, this course of action may be limited by signal-to-noise ratio requirements.

Even if the "constant slope" approximation is not a good one, it is likely that an instrument with symmetric spectral responsivity will give a more accurate reading than in the asymmetric case, and it can be argued that this criterion should also be met where possible.

A third criterion is concerned with the way the actual bandpass of the instrument differs from the required measurement bandpass. The spectral responsivity of a real radiometer tends to have the rounded shape of Fig. 3.4 (b), and the curve tends asymptotically to zero at either end of the bandpass region. Consequently, the wavelength limits  $\lambda_1$  and  $\lambda_2$  are ill defined. Moreover, the output signal is "weighted" in favour of the target radiance which coincides with the higher values of spectral responsivity. It is therefore suggested that the greatest accuracy will usually be achieved if the instrument is peak normalised (section 3.1.3.1), both for bandwidth and for the calibration responsivity.

#### 3.1.6.1 The Narrow-band Filter

If a narrower bandwidth can be tolerated, there are advantages in using a dielectric multilayer bandpass filter of the

"Fabry-Perot" type. A Fabry-Perot filter tends to have a rather well defined spectral transmission curve, which is highly symmetrical in the region of the bandpass. Our symmetry criterion is therefore satisfied, since the narrow-band filter will dominate the responsivity of the instrument.

Neglecting absorption, the filter transmission curve is closely approximated by the expression (Born and Wolf 1970):

$$T = \frac{1}{1 + F \sin^2\left(\frac{K}{\lambda}\right)} \quad \dots 3.12$$

where

$$F = \frac{4R}{(1-R)^2}$$

T = Transmission

R = Reflectance of dielectric "mirror"

K = Constant

Table 1 includes for comparison the output of an instrument with a Fabry-Perot filter of bandwidth 10 nm between "half power points". It is seen that the bandwidth reduction coupled with the symmetry can reduce the errors by a factor of 100 or more when compared to the MSS filter instruments.

### 3.1.7 SUMMARY AND CONCLUSIONS

In this paper we have reviewed some of the more fundamental problems associated with the measurement of target radiance, with particular reference to remote sensing of the environment. It is shown that although accurate radiance measurements can be made with either a very wide-band "spectrally flat" radiometer or conversely with an extremely narrow-band radiometer, difficulties arise in an "intermediate" bandwidth situation, where both targets spectral radiance and instrument spectral responsivity vary over the bandpass region.

These difficulties give rise to errors in radiance readings and can make the comparison of spectral signatures rather meaningless, when derived from different instruments.

The magnitude of these errors in a real situation is predicted by using the known spectral responsivities of the LANDSAT II Multi-Spectral Scanner, and those of aircraft and ground truth radiometers, to predict the instrument outputs obtained when viewing three "standard" targets. One "calibration" target is "spectrally flat", one has a spectral radiance with a constant positive slope, and one has a constant negative slope. It is seen that errors in radiance readings can exceed 25%, and for real targets, such as vegetation, these could be greater still.

We have shown that an instrument with symmetric spectral responsivity is capable of measuring accurately the radiance of a

target with any value of "constant slope" spectral radiance. Three criteria are suggested to minimise errors:

- (1) The use of an instrument with symmetric spectral responsivity.
- (2) Use of the peak-normalised calibration procedure and the peak-normalised bandpass to define the limits between which the radiance is measured.
- (3) Reduction of bandwidth if signal-to-noise considerations permit.

The possible advantages of using a dielectric multilayer Fabry-Perot filter to achieve (1) and (2) are discussed, and an example of the error reduction obtained with a Fabry-Perot type instrument is given.

### 3.1.8 REFERENCES

- M. BORN AND E. WOLF: "Principles of Optics", 4th edn, pp. 323-329, Pergamon, 1970.
- CIE AND IEC: "International Lighting Vocabulary", 3rd edn, Cie Publication No. 17 (E-1.1.), 1970.
- EBERHARDT, E. H.: Appl. Opt., 7, 2037, 1968.
- NICODEMUS, F. E.: "Normalisation in Radiometry" Appl. Opt., 12, 2960, 1973.
- NICODEMUS, F. E.: "Self Study Manual on Optical Radiation Measurements", NBS Technical Note 910-1, National Bureau of Standards, U.S.A., 1976.

TABLE 3.1—Output of real instruments viewing three "standard" targets of different spectral radiance

|                                   | MSS BAND | DETECTOR | Normal<br>Bandwidth<br>nm | Peak<br>Normalised<br>Bandwidth<br>nm | OUTPUT WHEN VIEWING TARGET |               |               |
|-----------------------------------|----------|----------|---------------------------|---------------------------------------|----------------------------|---------------|---------------|
|                                   |          |          |                           |                                       | Target<br>(1)              | Target<br>(2) | Target<br>(3) |
| LANDSAT II MULTI-SPECTRAL SCANNER | 4        | A        | 100                       | 93.92                                 | 1.000                      | 0.985         | 1.020         |
|                                   | "        | B        | "                         | 99.23                                 | "                          | 0.975         | 1.037         |
|                                   | "        | C        | "                         | 96.54                                 | "                          | 1.010         | 1.006         |
|                                   | "        | D        | "                         | 99.16                                 | "                          | 0.967         | 1.044         |
|                                   | "        | E        | "                         | 100.16                                | "                          | 0.973         | 1.035         |
|                                   | "        | F        | "                         | 98.85                                 | "                          | 0.990         | 1.016         |
|                                   | 5        | A        | 100                       | 101.35                                | 1.000                      | 1.185         | 0.814         |
|                                   | "        | B        | "                         | 97.11                                 | "                          | 1.144         | 0.852         |
|                                   | "        | C        | "                         | 97.61                                 | "                          | 1.156         | 0.843         |
|                                   | "        | D        | "                         | 99.81                                 | "                          | 1.159         | 0.836         |
|                                   | "        | E        | "                         | 98.36                                 | "                          | 1.166         | 0.832         |
|                                   | "        | F        | "                         | 100.04                                | "                          | 1.177         | 0.821         |
|                                   | 6        | A        | 100                       | 104.62                                | 1.000                      | 1.043         | 0.954         |
|                                   | "        | B        | "                         | 107.70                                | "                          | 0.985         | 1.017         |
|                                   | "        | C        | "                         | 100.75                                | "                          | 0.967         | 1.040         |
|                                   | "        | D        | "                         | 99.66                                 | "                          | 0.965         | 1.041         |
|                                   | "        | E        | "                         | 104.38                                | "                          | 1.015         | 0.996         |
|                                   | "        | F        | "                         | 98.65                                 | "                          | 0.956         | 1.049         |
|                                   | 7        | A        | 300                       | 182.75                                | 1.000                      | 0.767         | 1.240         |
|                                   | "        | B        | "                         | 173.32                                | "                          | 0.747         | 1.262         |
|                                   | "        | C        | "                         | 179.63                                | "                          | 0.766         | 1.244         |
|                                   | "        | D        | "                         | 177.86                                | "                          | 0.763         | 1.247         |
|                                   | "        | E        | "                         | 178.53                                | "                          | 0.760         | 1.248         |
|                                   | "        | F        | "                         | 174.54                                | "                          | 0.757         | 1.250         |

TABLE 3.1 (continued)

| Instrument             | MSS Band | Detector | Nominal Bandwidth nm          | Peak Normalised Bandwidth | Output when viewing target |            |            |
|------------------------|----------|----------|-------------------------------|---------------------------|----------------------------|------------|------------|
|                        |          |          |                               |                           | Target (1)                 | Target (2) | Target (3) |
| Aircraft Radiometer    | 4        |          | 100                           | 93.22                     | 1.000                      | 1.057      | 0.943      |
|                        | 5        |          | 100                           | 94.12                     | "                          | 1.071      | 0.92       |
|                        | 6        |          | 100                           | 90.20                     | "                          | 0.786      | 1.212      |
|                        | 7        |          | 300                           | 154.62                    | "                          | 0.606      | 1.394      |
|                        |          |          |                               |                           |                            |            |            |
| "Gamma" Radiometer     | 4        |          | 100                           | 71.24                     | 1.000                      | 0.915      | 1.08       |
|                        | 5        |          | 100                           | 104.54                    | "                          | 1.142      | 0.858      |
|                        | 6        |          | 100                           | 124.36                    | "                          | 1.016      | 0.98       |
|                        | 7        |          | 300                           | 264.61                    | "                          | 0.701      | 1.299      |
|                        |          |          |                               |                           |                            |            |            |
| "Exotech" Radiometer   | 4        |          | 100                           | 93.35                     | 1.000                      | 1.029      | 0.95       |
|                        | 5        |          | 100                           | 126.86                    | "                          | 0.818      | 1.177      |
|                        | 6        |          | 100                           | 135.91                    | "                          | 1.092      | 0.87       |
|                        | 7        |          | 300                           | 174.58                    | "                          | 0.435      | 1.565      |
|                        |          |          |                               |                           |                            |            |            |
| Fabry-Perot Radiometer | 6        |          | Half-power Bandwidth nm<br>10 | 13.34                     | 1.000                      | 1.002      | 0.99       |

TABLE 3.2—Band Ratios for the different instruments when viewing "standard" targets.

| Instrument             | Detector | Both<br>Band<br>Ratios<br>Target (1) | Ratio MSS 4/7 |               | Ratio MSS 5/7 |               |
|------------------------|----------|--------------------------------------|---------------|---------------|---------------|---------------|
|                        |          |                                      | Target<br>(2) | Target<br>(3) | Target<br>(2) | Target<br>(3) |
| LANDSAT II MSS         | A        | 1.000                                | 1.284         | 0.823         | 1.545         | 0.656         |
|                        | B        | "                                    | 1.305         | 0.822         | 1.531         | 0.675         |
|                        | C        | "                                    | 1.319         | 0.809         | 1.509         | 0.678         |
|                        | D        | "                                    | 1.267         | 0.837         | 1.519         | 0.670         |
|                        | E        | "                                    | 1.280         | 0.829         | 1.534         | 0.667         |
|                        | F        | "                                    | 1.308         | 0.813         | 1.555         | 0.657         |
| Aircraft<br>Radiometer |          | 1.000                                | 1.744         | 0.676         | 1.650         | 0.686         |
| Gamma<br>Radiometer    |          | 1.000                                | 1.305         | 0.835         | 1.629         | 0.661         |
| Exotech<br>Radiometer  |          | 1.000                                | 2.366         | 0.613         | 1.880         | 0.752         |

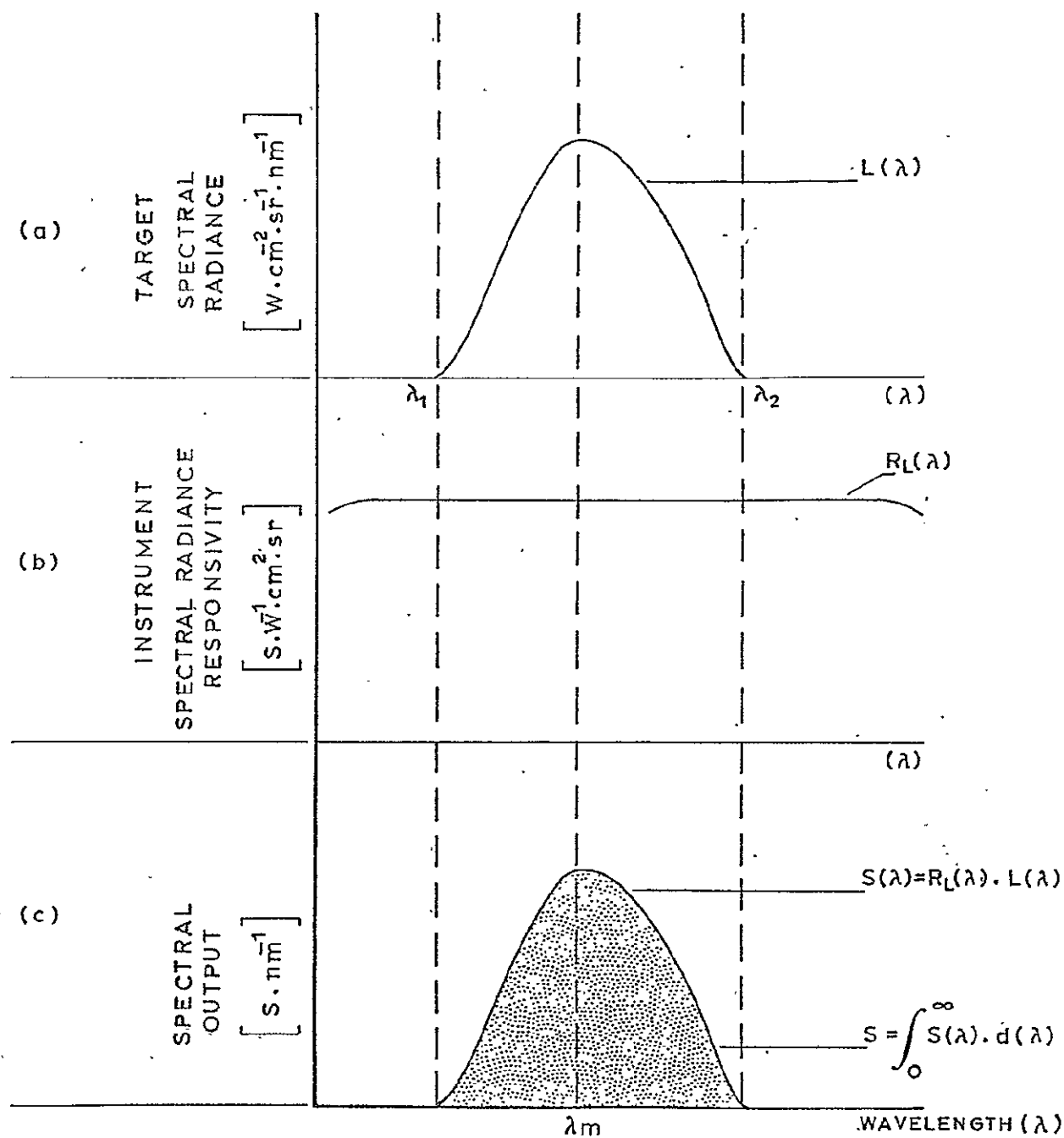


FIG. 3.1 SPECTRALLY FLAT RADIOMETER VIEWING TARGET of VARYING SPECTRAL RADIANCE

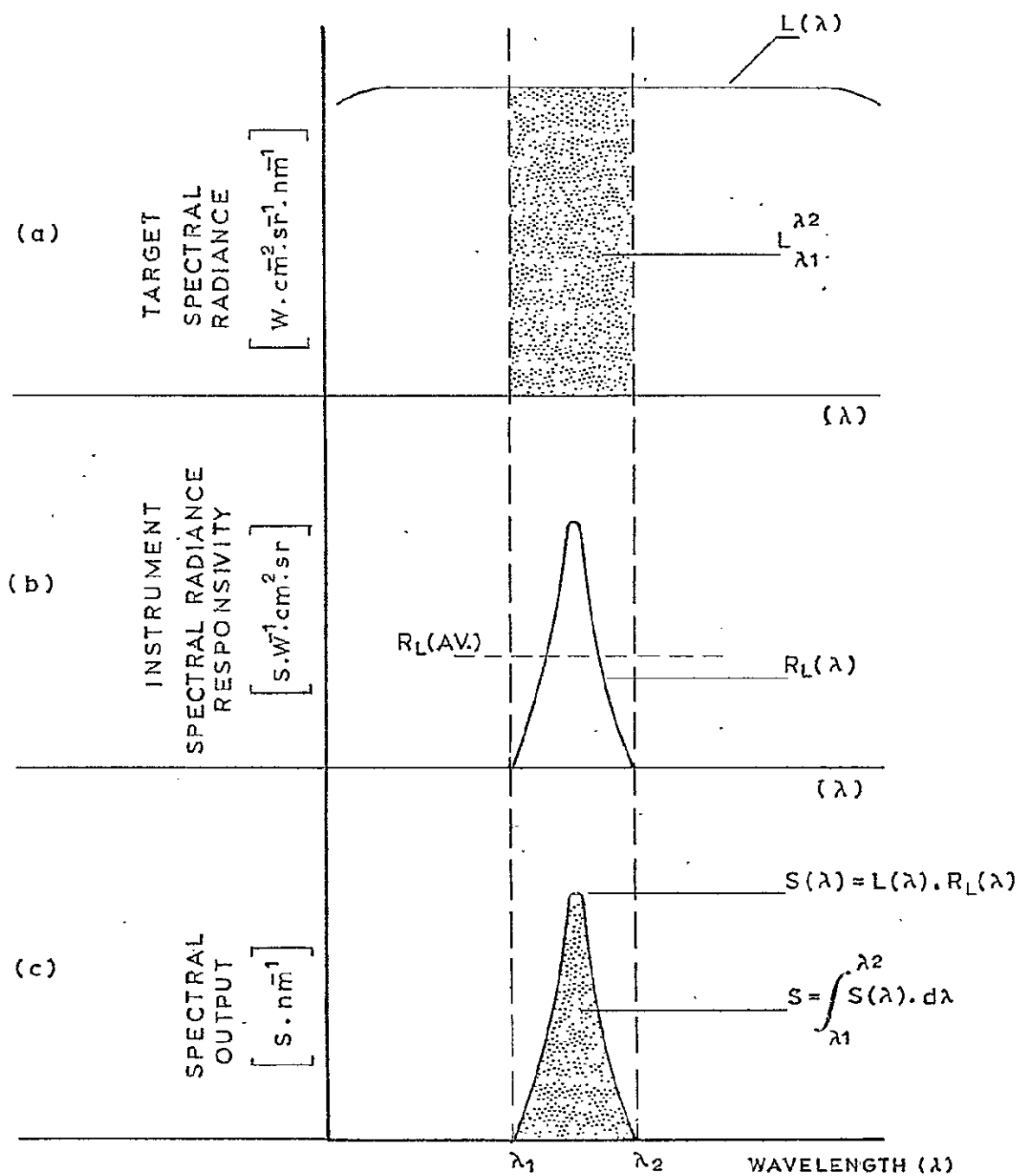


FIG. 3.2 "NARROW-BAND" RADIOMETER VIEWING "SPECTRALLY FLAT" TARGET



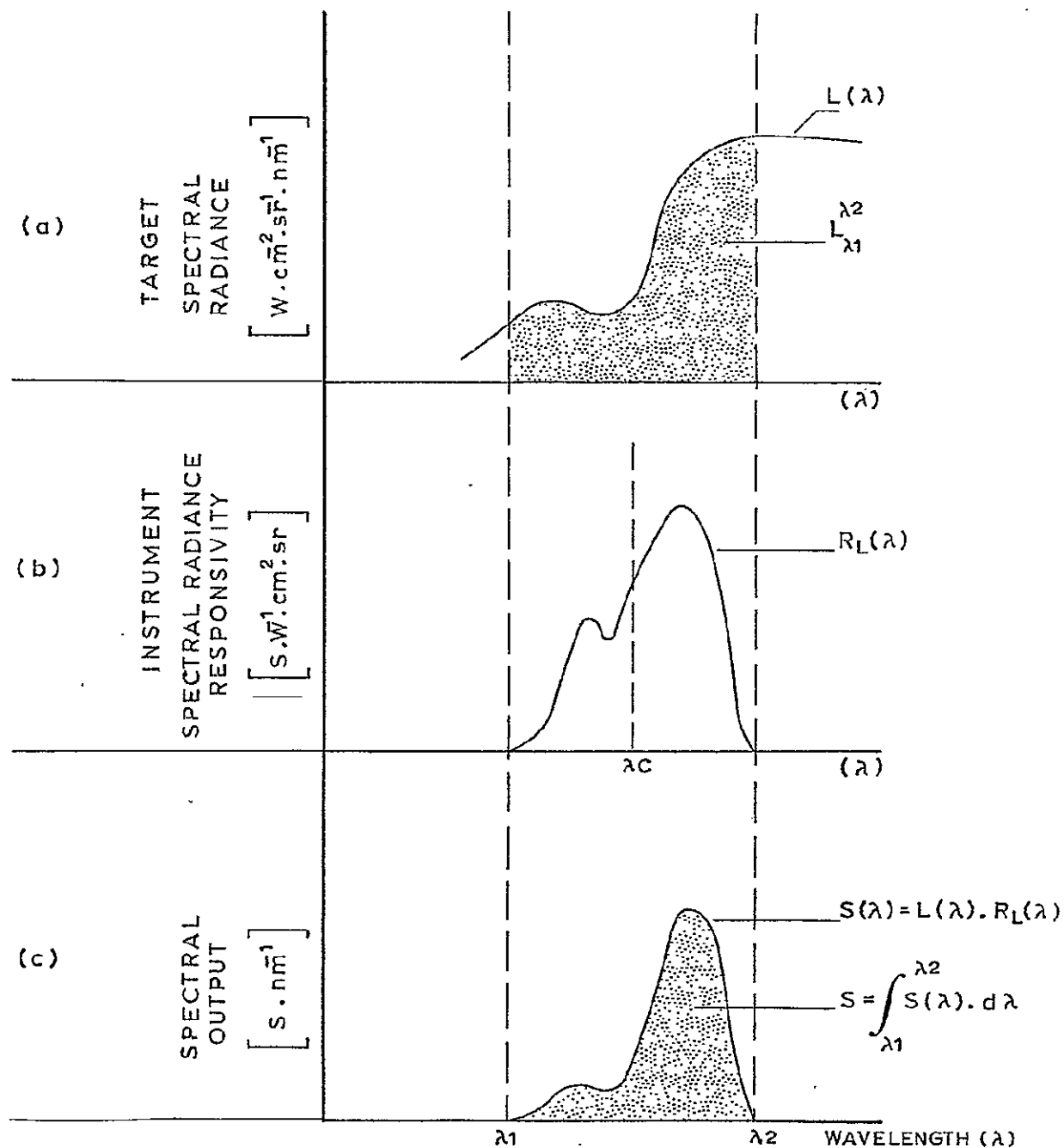


FIG.3.3 INTERMEDIATE BANDWIDTH INSTRUMENT VIEWING SPECTRALLY VARYING TARGET

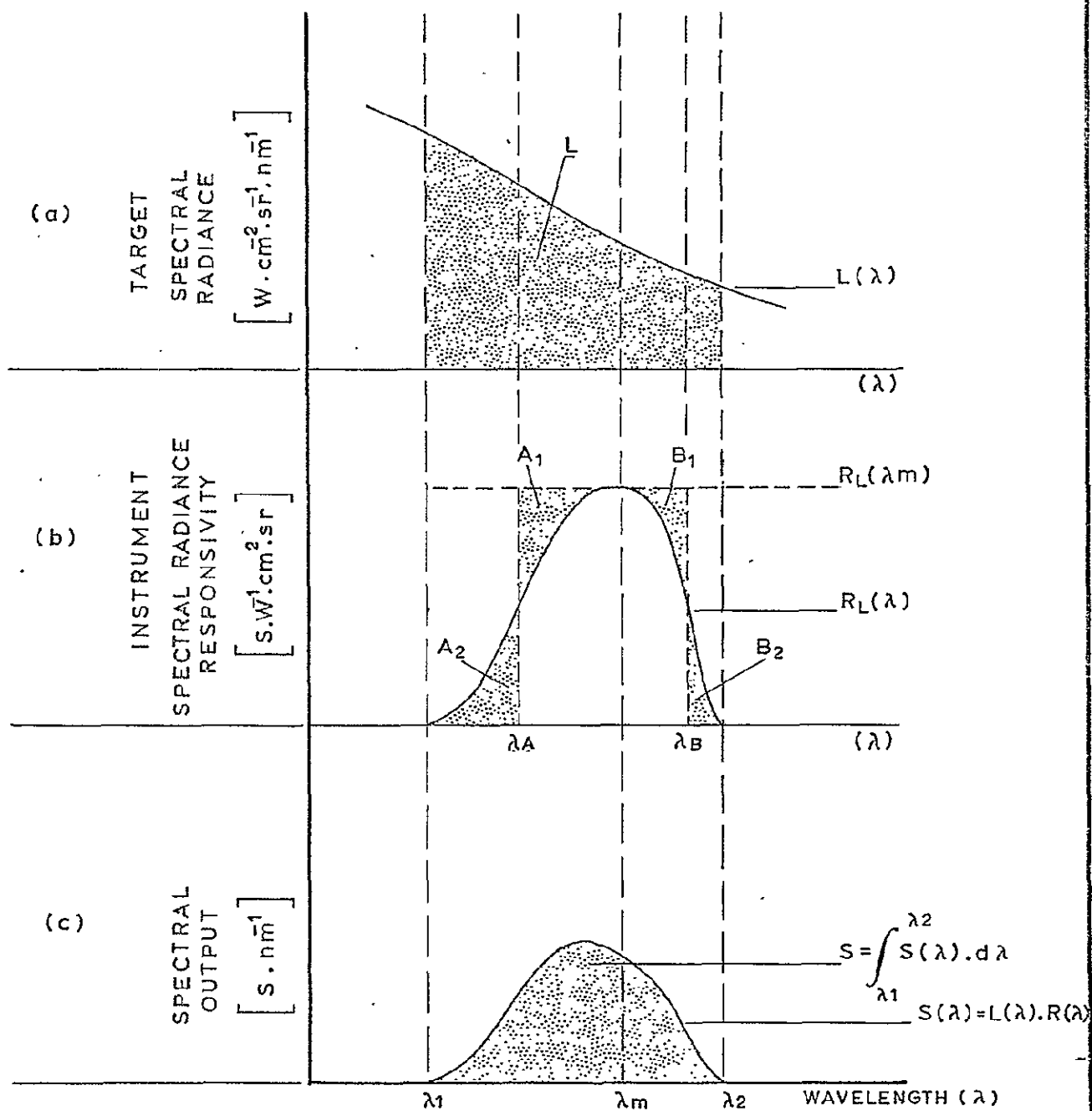


FIG. 3.4 PEAK NORMALISATION

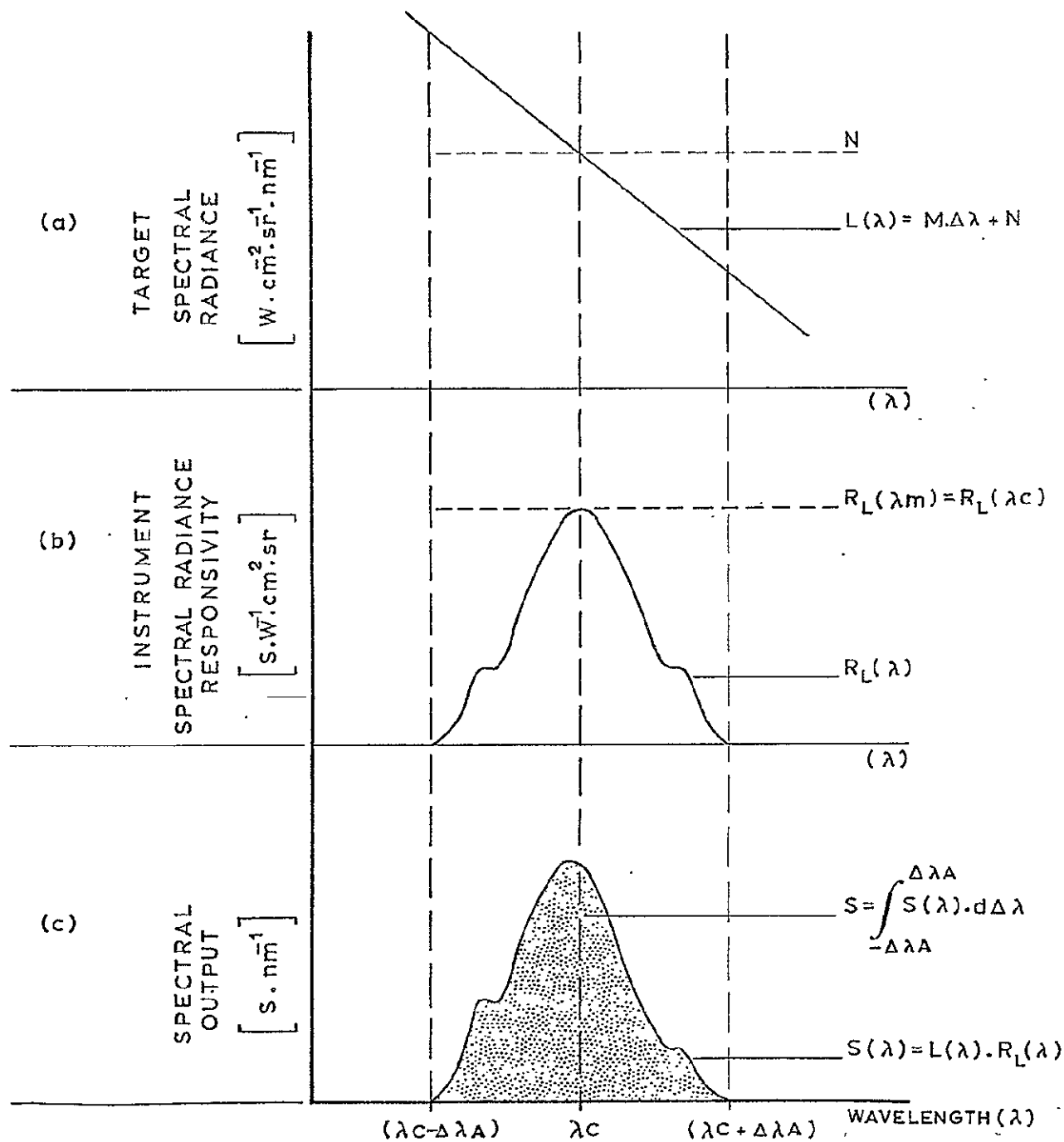


FIG. 3.5 GENERAL CASE of SYMMETRIC SPECTRAL RESPONSIVITY

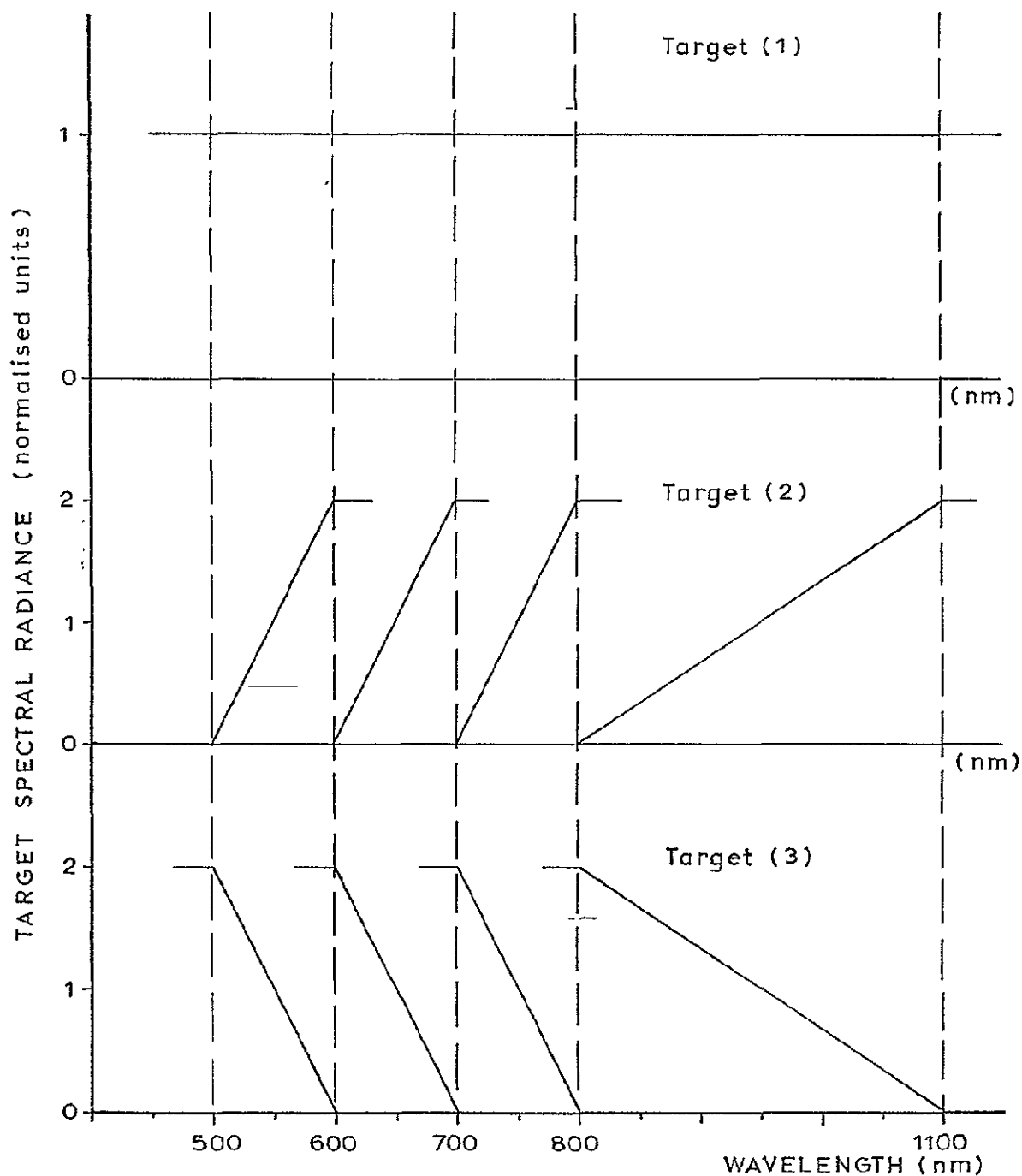


FIG. 3.6 SPECTRAL RADIANCES of 'STANDARD' TARGETS WITH EQUAL RADIANCE VALUES WITHIN EACH MSS BAND

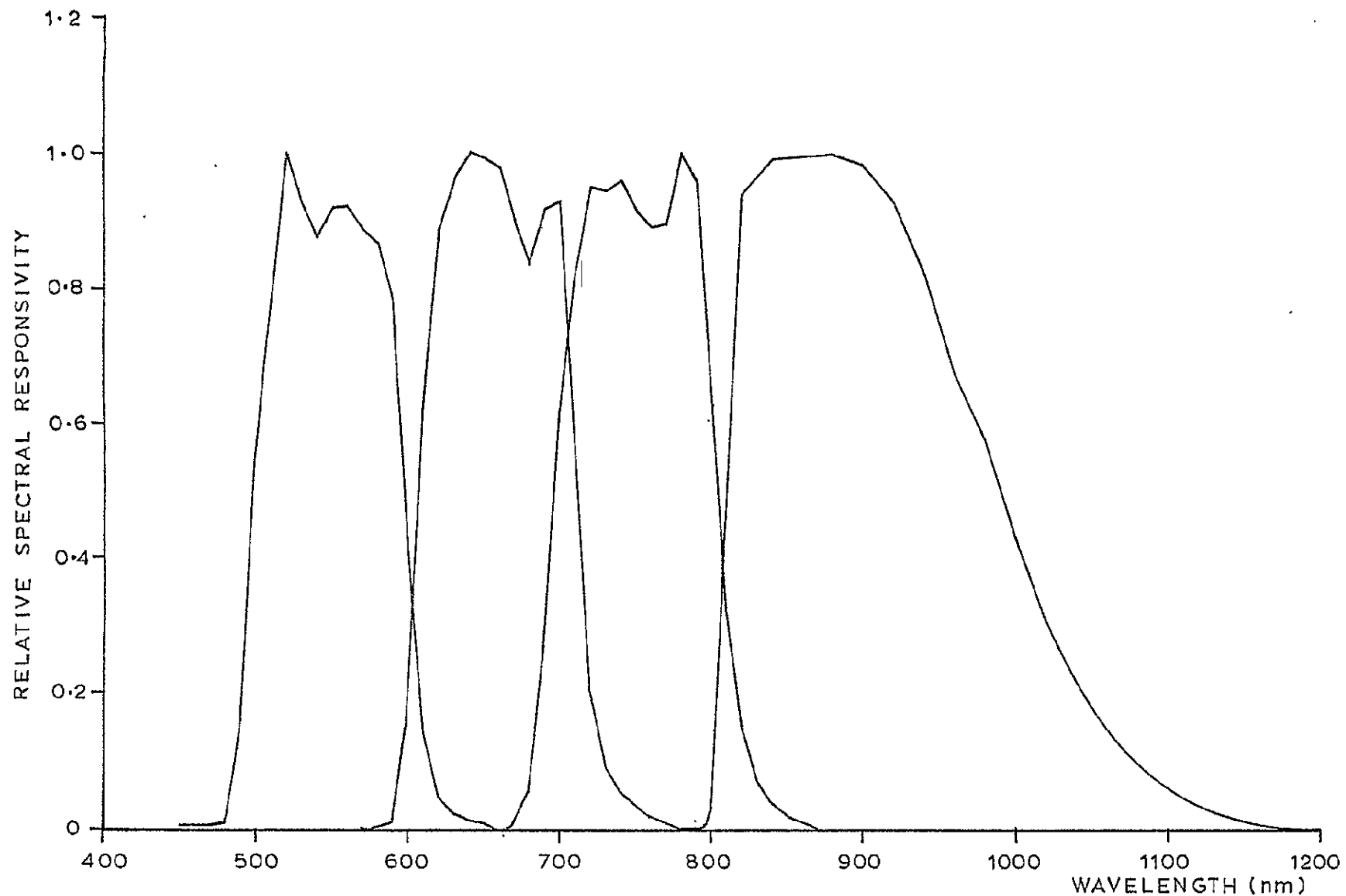


FIG. 3.7 RELATIVE SPECTRAL RESPONSIVITY of  
LANDSAT II MULTI-SPECTRAL SCANNER

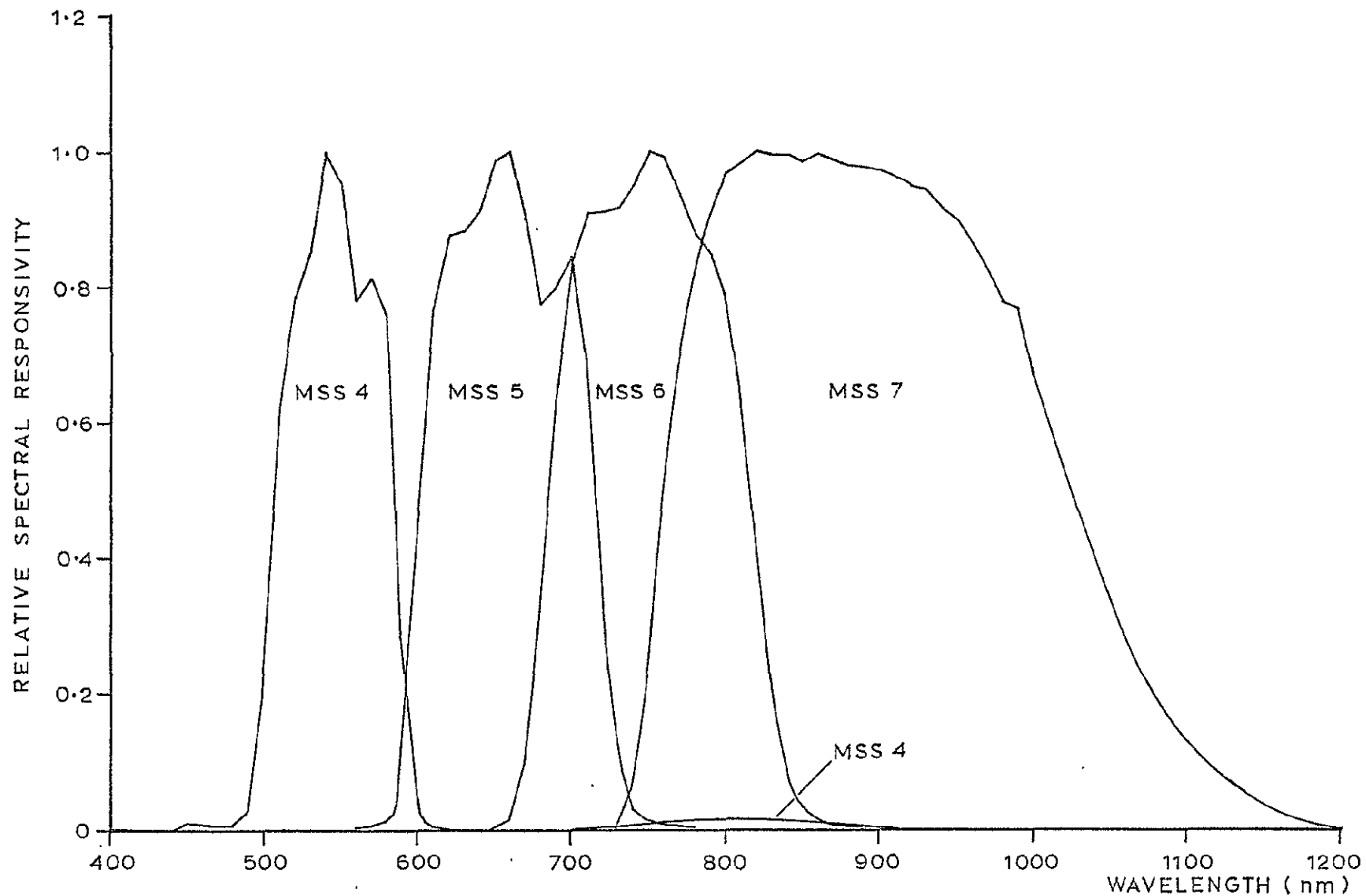


FIG. 3.8 RELATIVE SPECTRAL RESPONSIVITY of  
"GAMMA" GROUND TRUTH RADIOMETER

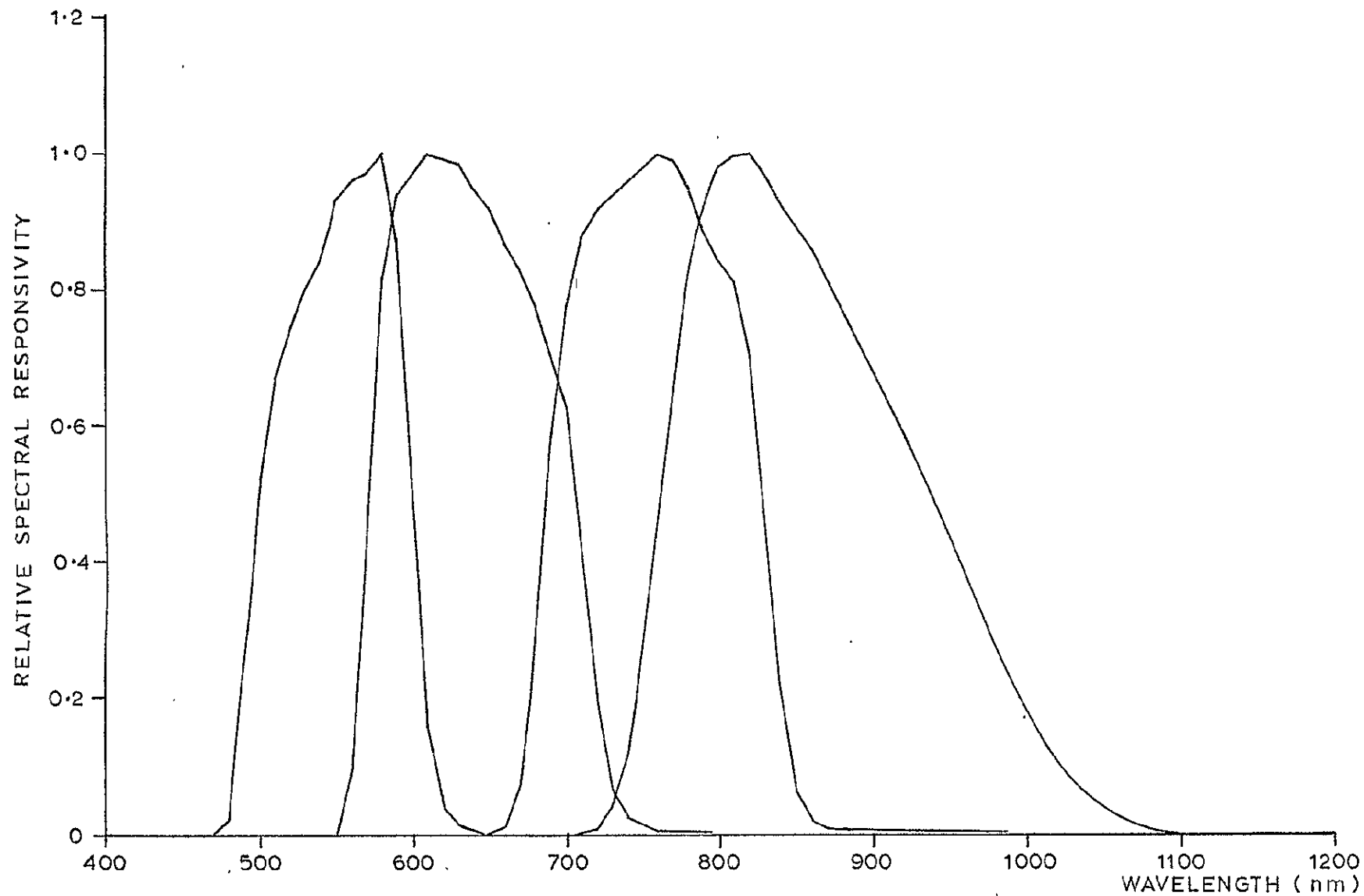


FIG. 3.9 RELATIVE SPECTRAL RESPONSIVITY of  
"EXOTECH" GROUND TRUTH RADIOMETER

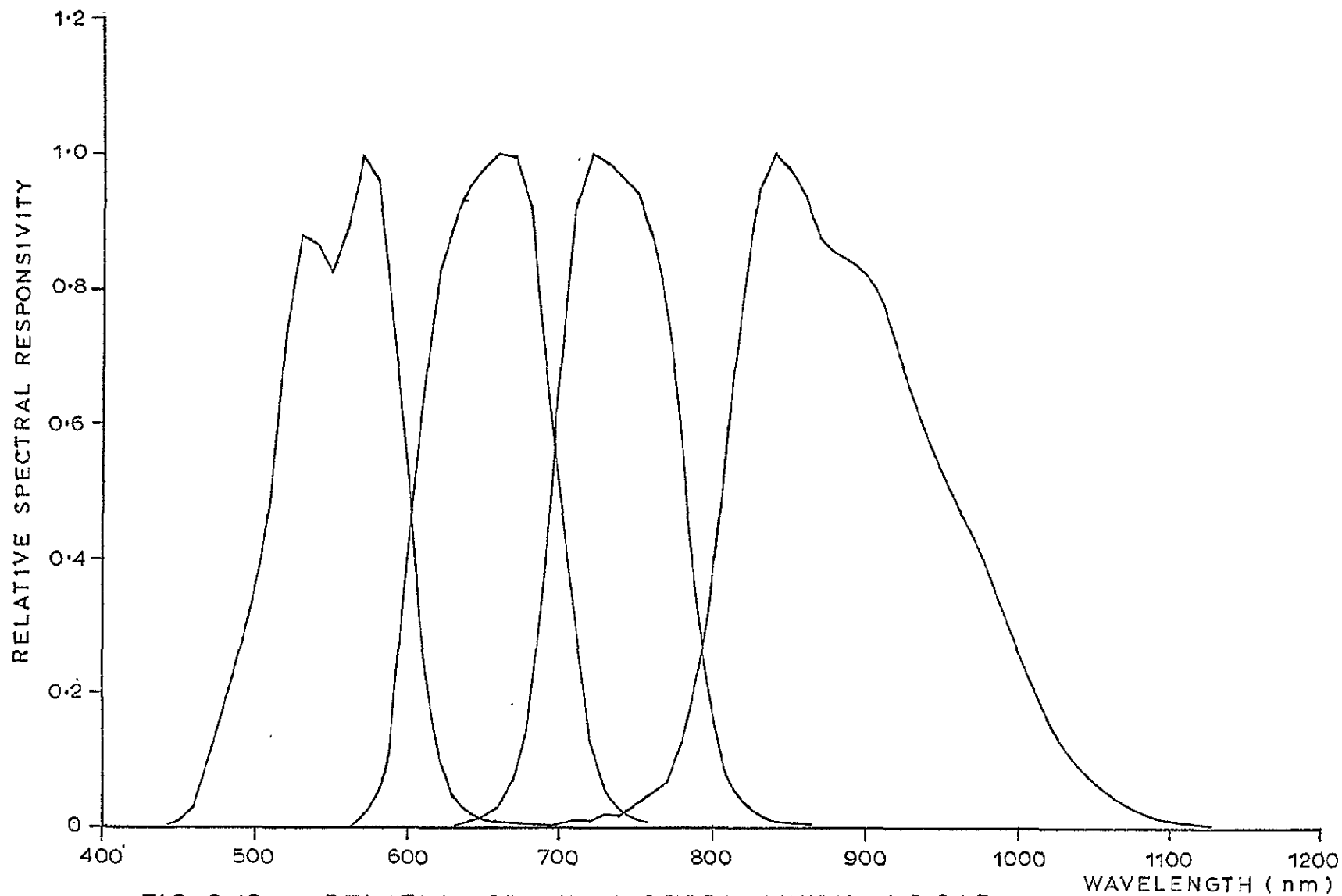


FIG. 3.10 RELATIVE SPECTRAL RESPONSIVITY of D.S.I.R. AIRCRAFT RADIOMETER



## APPENDIX TO 3.1

Terms, definitions, and units

(a) Terms associated with the target

( ) = Symbol

[ ] = Units (typical)

- RADIANT FLUX : The radiant power incident on or reflected from a target. ( $\Phi$ ) [W]
- FLUX DENSITY : The flux per unit target area, defined as EXITANCE when leaving target and IRRADIANCE when incident on target. (M)-EXITANCE:(E)-IRRADIANCE. [ $\text{W.m}^{-2}$ ] or [ $\text{W.cm}^{-2}$ ]
- SPECTRAL RADIANT FLUX : Radiant flux per unit wavelength. ( $\Phi(\lambda)$ ). [ $\text{W.}\mu\text{m}^{-1}$ ] or [ $\text{W.nm}^{-1}$ ]
- GLOBAL IRRADIANCE : The incident power density on a horizontal terrestrial target due to radiation from sun and sky. ( $E_G$ ). [ $\text{W.m}^{-2}$ ] or [ $\text{W.cm}^{-2}$ ]
- SOLAR IRRADIANCE : The incident power density on a terrestrial target with surface normal to the sun's rays, due to radiation from sun only. ( $E_s$ ). [ $\text{W.m}^{-2}$ ] or [ $\text{W.cm}^{-2}$ ]
- SPECTRAL IRRADIANCE : The incident power density per unit wavelength. ( $E(\lambda)$ ). [ $\text{W.m}^{-2}.\mu\text{m}^{-1}$ ] or [ $\text{W.cm}^{-2}.\text{nm}^{-1}$ ]
- RADIANCE : The flux (power) leaving a target in a specified direction, per unit projected target area, per unit solid angle (L). [ $\text{W.m}^{-2}.\text{sr}^{-1}$ ]
- SPECTRAL RADIANCE : The target radiance per unit wavelength (L). [ $\text{W.m}^{-2}.\text{sr}^{-1}.\mu\text{m}^{-1}$ ] or [ $\text{W.cm}^{-2}.\text{sr}^{-1}.\text{nm}^{-1}$ ]

(b) Terms associated with the sensor

- OUTPUT : The output produced by the radiometer in response to an incident flux (power) from any source or target. (s). [s] where s is a generalised unit which may for instance be volts or amps.
- SPECTRAL OUTPUT : The output per unit wavelength. ( $s(\lambda)$ ). [ $\text{s.}\mu\text{m}^{-1}$ ] or [ $\text{s.nm}^{-1}$ ]
- SPECTRAL POWER RESPONSIVITY : The output s per unit incident monochromatic flux (power) at the entrance aperture. ( $R_\Phi(\lambda)$ ). [ $\text{s.W}^{-1}$ ]

SPECTRAL RADIANCE  
RESPONSIVITY

: The output  $s$  per unit monochromatic target radiance seen by sensor.  
 $(R_L(\lambda)) \cdot [s \cdot w^{-1} \cdot m^2 \cdot sr]$  or  
 $[s \cdot w^{-1} \cdot cm^2 \cdot sr]$

RELATIVE SPECTRAL  
RESPONSIVITY

: The responsivity at wavelength  $\lambda$ , divided by a normalising quantity such as  $R(\lambda_m)$  where  $R(\lambda_m)$  is the peak responsivity.  
 $(r(\lambda)) \cdot [dimensionless]$

### 3.2 LANDSAT RADIOMETRIC ACCURACY

M. J. McDonnell

The second part of this chapter describes an attempt which has been made to assess the absolute radiometric accuracy of linear (i.e., decompressed) digital data from the LANDSAT multispectral scanner. This assessment was done by comparing the average LANDSAT signature for a target area with the corresponding signature derived from a single line scan produced by our Hasselblad camera radiometer during an aerial survey. This radiometer has been shown to be linear over its dynamic range.

The target area chosen was that part of the wide shingle bed of the Waimakariri River just north of Darfield, mid-Canterbury, which had been scanned by the radiometer. This area was chosen because it is easy to identify on the LANDSAT CCT from an inch to the mile map on which is superimposed the radiometer line scan. Also the radiometer signature for shingle in the four LANDSAT bands should be only slightly affected by the exact positioning of the line scan across the riverbed. This positioning error was less than 100 m. The LANDSAT II scene chosen (2282-21254) was taken at 2125 hrs on 31 October 1975 (GMT) with a sun elevation angle of  $43^\circ$ . The corresponding signature for the riverbed target in the four MSS bands is shown in column (a) of Table 3.3. This signature was deduced by inspection of coded CCT printouts. For each band and maximum CCT reading the corresponding absolute radiance within the filter pass band is shown in column (a) of Table 3.4. This radiance data for LANDSAT II was published in a July 1977 LANDSAT Newsletter bulletin. The LANDSAT data have been corrected by NASA and are, to a good approximation, linear.

The scan with the airborne radiometer at an altitude of 17,000 ft was made at 2200 hrs on 14 November 1975 (GMT) with a sun elevation angle of  $52^\circ$ . The radiometer signature for the riverbed is shown in column (b) of Table 3.3. Apart from sun angle effects, this signature should have changed little during the two weeks since the LANDSAT overpass. However, the radiometer valves are too high for a fair comparison with LANDSAT. This is due to the higher sun angle of elevation and the consequent decrease in atmospheric absorption of incident radiation. Another error source is the atmospheric absorption above 17,000 ft of reflected radiation reaching the satellite. The radiometer signature was compensated for these effects to give the result shown in column (c) of Table 3.3. This result is what would have been given by the radiometer at the time of the LANDSAT readings if its position and field of view had coincided with LANDSAT. The first two errors could be easily corrected, and the third was approximately corrected using the results given in Table 4.2 of chapter 4 of this report, assuming half the total atmospheric absorption in each band occurs above 17,000 ft. The riverbed was assumed to be a diffuse reflector.

In order to make a fair comparison between the readings obtained from LANDSAT and the radiometer, both instruments should be calibrated in the same way against a standard light source.

If this is done the instruments would agree when looking at a target whose reflected spectral radiance is proportional to the calibration source. However, in general they would not agree when looking at any other target, as pointed out in section 3.1.4.3. This is due to the differing responses of the "intermediate" band filters used in the two instruments.

The LANDSAT MSS has been calibrated against a spectrally flat radiant source. For generality, however, we present our results calibrated against three light sources (A,B,C) whose spectral radiances are shown in Fig. 3.1. Light source A is Standard Lamp No. 178A operating at 2854°K. This source has been found to be in close agreement with a standard Australian source. Light source B is an ideal white light source, and C is a set of ideal light sources which, for each nominal LANDSAT passband, have uniform spectral radiance within and zero outside the passband. Calibration against A was achieved by using it, at a distance of 40 cm, to illuminate a barium sulphate plate with a diffuse reflectance of 0.98. This plate was viewed in turn by each band of the Hasselblad radiometer, filling the field of view of the appropriate camera focused at infinity, and giving a radiometer reading which was noted. The final step was simply to multiply the radiometer readings in each band by a scaling factor such that they would give the same reading as a nominal LANDSAT MSS radiometer channel when viewing A. Calibration against ideal sources B and C was achieved using the results for A and the known relative spectral responsivities of our Hasselblad MSS radiometer. For B this is achieved by first normalising each tabulated relative spectral responsivity so that the area under the responsivity curve is the same as that for the corresponding nominal LANDSAT filter. This is illustrated in Fig. 3.12 (b). Similarly, for C, each responsivity curve is normalised so that the area under it, within the nominal LANDSAT passband, is the same as that for the nominal LANDSAT filter (see Fig. 3.12 (c)). Note that as it is intended that the radiometer should measure radiance, the final outputs (see Appendix to section 3.1) of the calibrated radiometer should be in units of  $W.m^{-2}.sr^{-1}$ . Therefore, the spectral radiance responsivities should be in dimensionless units which we have called relative spectral responsivity  $r(\lambda)$  (see Appendix 3.1). For the radiometer to be calibrated against B, the absolute radiance corresponding to the radiometer reading made while calibrating A is obtained by integrating over wavelength the product of the relative spectral responsivity normalised for B (Fig. 3.12 (b)) and the spectral radiance of A (Fig. 3.11 (a)). This gives the scaling factor required to calibrate the radiometer. The radiometer can be calibrated against C in the same way. The LANDSAT MSS has actually been calibrated against source B.

The calibration results obtained above for A, B, and C were then scaled, using the results in Table 3.3, to give the absolute radiances (in columns (b) - (d) of Table 3.4) corresponding to the maximum CCT readings. The effect of the different light sources used in calibration is seen to give a spread of up to about  $\pm 15\%$  in the results with respect to B. This is a significant error. The published results for LANDSAT II in Table 3.4 differ from those for B by 43, 22, 29, and -13% respectively for the four MSS bands. We are satisfied that our investigation has

been carried out as carefully as possible. It is unfortunate that our aircraft coverage was not coincident with that of LANDSAT. However, this time difference has been carefully compensated for, and we feel that it does not fully explain the discrepancies we have found. For example, it might contribute at worst an error of some 20% on the measurements for B.

Another possible contributor to the difference between our results for B and those for LANDSAT is the detailed spectral radiance of the target itself, which we do not know. However, let us assume that the detailed spectral radiance of the target within each nominal LANDSAT passband, is at worst of the form of a slope function discussed in section 3.1.5. Table 3.1 can then be used to estimate the maximum consequent discrepancy between the LANDSAT II published results and those for B for each band. These errors, expressed as a percentage of the results for B, are 8, 10, 20, and 15% respectively.

On the basis of the above estimates of the errors involved in our work we consider that our calibration results are essentially in agreement with the published results for LANDSAT II, although our results for MSS band 4 are slightly lower than might have been expected. We stress that the effect of the spectral radiance of the calibration source and target on the calibration results is usually significant.

Horan et al. (1975, 1974) have also checked the radiometric accuracy of LANDSAT II. However, although their measurements may well have been more accurate than ours, they do not seem to have taken into account the effect of the spectral radiance of the calibration source and target, which we think is important and could significantly alter their results.

### 3.2.1. REFERENCES

Horan, J. J., Schwartz, D. S., Love, J. D. (1974): "Partial performance degradation of a remote sensor in a space environment and some probable causes" Appl. Opt. 13 (5) 1230.

Horan, J. J., Schwartz, D. S., Love, J. D. (1975): "In orbit sun calibration performance of LANDSAT II", Appl. Opt. 14 (9) 2053.

Table 3.3 - Riverbed readings for the four MSS bands for (a) LANDSAT II on 31 October 1975, (b) Hasselblad camera radiometer on 14 November 1975, (c) corrected radiometer readings.

| MSS band | (a)<br>LANDSAT | (b)<br>radiometer | (c)<br>corrected<br>radiometer |
|----------|----------------|-------------------|--------------------------------|
| 4        | 31.6           | 54.9              | 42.2                           |
| 5        | 35.0           | 39.4              | 31.5                           |
| 6        | 29.7           | 45.1              | 36.7                           |
| 7        | 8.5            | 27.9              | 22.3                           |

Table 3.4 - Maximum CCT readings for the four LANDSAT MSS bands and the corresponding absolute radiance within the nominal filter passband for (a) as specified for LANDSAT II; and as deduced from our radiometer readings using light sources (b) A, (c) B, and (d) C.

| MSS band | Maximum<br>CCT level | mw/cm <sup>2</sup> /sr |          |          |          |
|----------|----------------------|------------------------|----------|----------|----------|
|          |                      | (a)<br>LANDSAT II      | (b)<br>A | (c)<br>B | (d)<br>C |
| 4        | 127                  | 2.63                   | 1.72     | 1.84     | 2.20     |
| 5        | 127                  | 1.76                   | 1.38     | 1.44     | 1.64     |
| 6        | 127                  | 1.52                   | 1.18     | 1.18     | 1.30     |
| 7        | 63                   | 3.91                   | 4.56     | 4.50     | 4.66     |

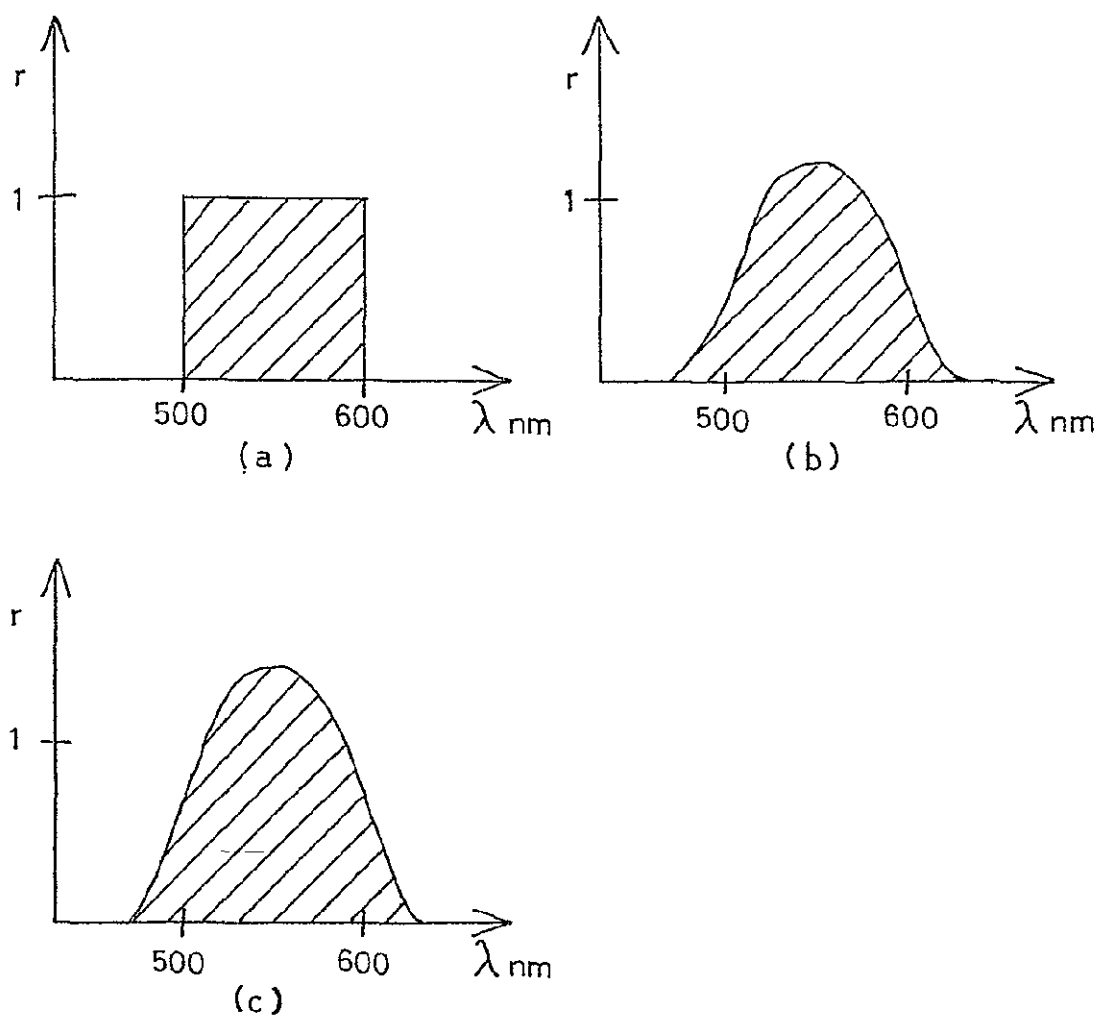


Fig. 3.12 - Relative spectral responsivity  $r(\lambda)$  for MSS band 4 for: (a) nominal LANDSAT MSS; Hasselblad radiometer normalised for (b) B and (c) C. All the shaded areas are equal.

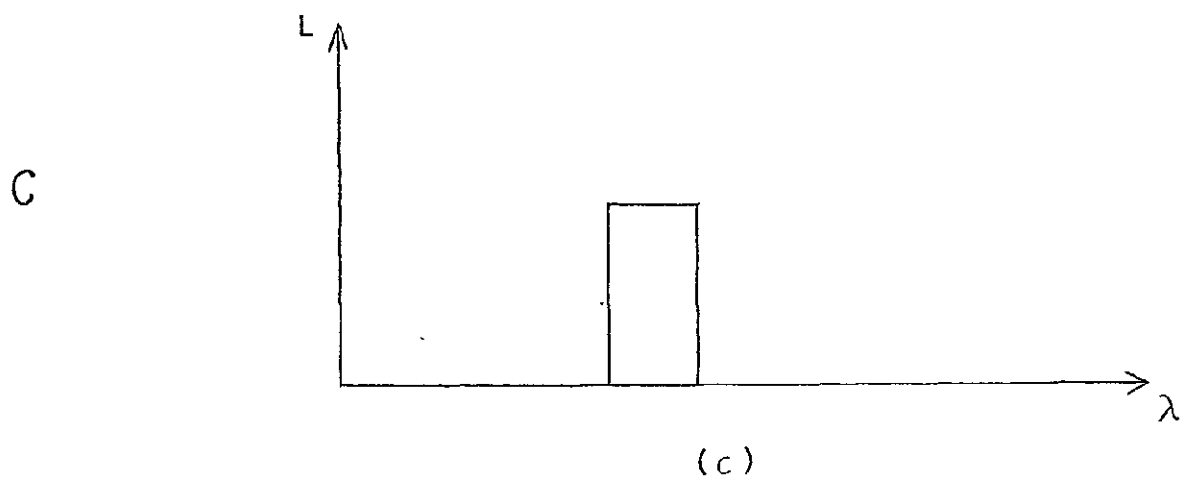
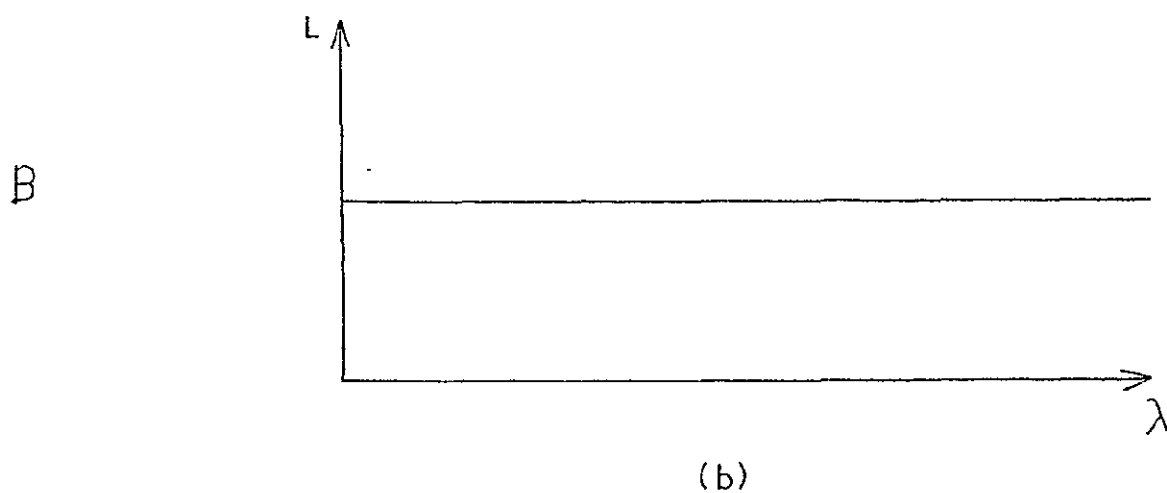
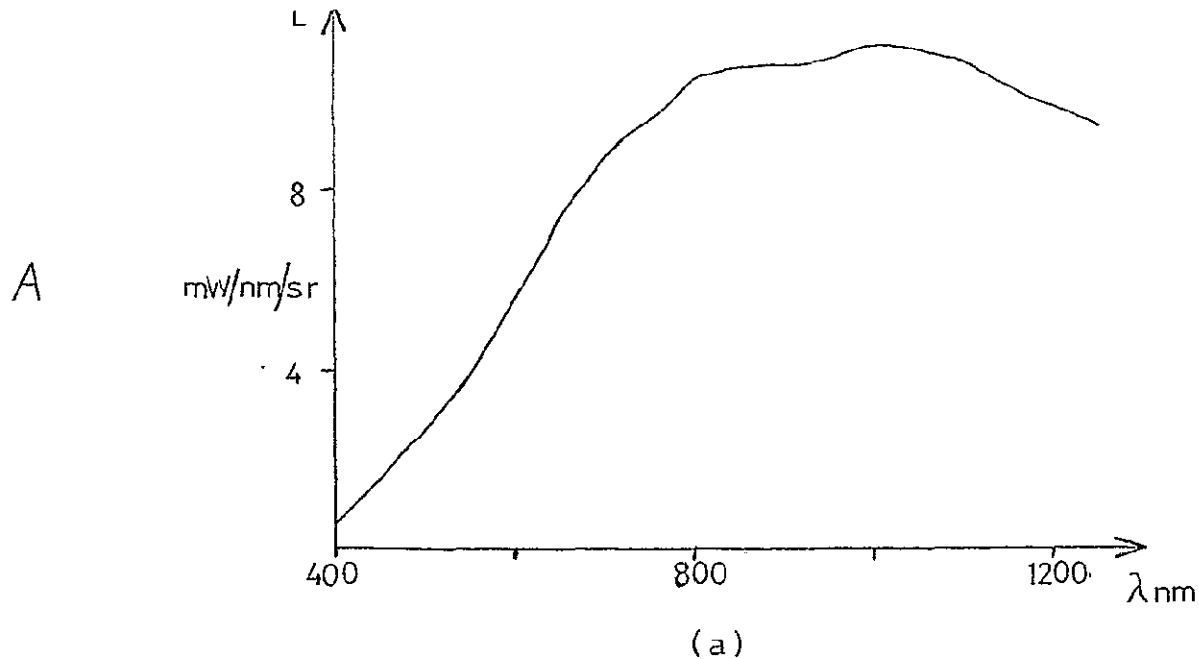


Fig. 3.11 - Spectral radiance  $L(\lambda)$  plotted against wavelength  $\lambda$  for three standard light sources: (a) A - Standard Lamp No. 178A at  $2854^\circ\text{K}$ , (b) B - ideal white light source, (c) C - ideal light source set which, for each nominal LANDSAT filter, has uniform response within and zero outside the passband.



## CHAPTER 4

## ATMOSPHERIC MEASUREMENTS

P J Ellis and M J Duggin

## ABSTRACT

A ground radiometer utilising the LANDSAT MSS spectral bands has been used to measure atmospheric extinction coefficients in New Zealand and Australia, and to estimate the extra-terrestrial solar irradiances in each MSS band. The irradiances derived from this laboratory calibrated instrument are in good agreement with the proposed standard zero-airmass solar irradiances. Diurnal variations of extinction coefficient are shown for test sites in the two countries, and beam transmittances derived from these measurements are compared with similar measurements in the Northern Hemisphere.

## CHAPTER 4

## ATMOSPHERIC MEASUREMENTS

P J Ellis and M J Duggin

4.1 INTRODUCTION

During the course of the LANDSAT II investigation programme, studies of atmospheric transmission in the LANDSAT MSS spectral bands have been made in New Zealand and Australia and the results compared with those from a similar study in the U.S.A. The New Zealand and Australian measurements have all been made with a "Gamma Scientific" radiometer at selected test sites in the two countries. This instrument has a four position filter wheel in which the spectral transmissions of the bandpass filters approximate to those of the LANDSAT Multi-Spectral Scanner.

The radiometer is typically used to measure solar irradiance (3.1 APPENDIX) at intervals throughout a single day. These measurements are confined to a maximum period of eight hours centred on "solar noon" and are only made on cloud-free days.

We assume that the effect of the atmosphere on solar irradiance at ground level can be described by a simple atmospheric model. The computer is used to modify the parameters in this model until a "least squares fit" to the measured data is obtained. One of the parameters so derived is the solar irradiance at the top of the atmosphere and the other is the atmospheric extinction coefficient. These two quantities are derived for each MSS spectral band. The solar spectral irradiance at the top of the atmosphere has been measured by a number of workers and a proposed "standard" based on these results is reported by Thekaekara (1972). We have calculated the output of the radiometer in each band that would be produced by this "extra terrestrial" solar source, and compared these values to those derived from the atmospheric model. The comparison serves as a useful check of the validity of our data and of the radiometer calibration.

4.2 OBJECTIVES

(a) To use a "calibration lamp" in the laboratory to calibrate the radiometer in units of irradiance.

(b) To measure the global and solar irradiance as defined in 3.1 APPENDIX at test sites in New Zealand and Australia, over a period of years in order to establish the likely absolute values and short and long term fluctuations.

(c) To use data gathered in the course of several cloud-free days to determine the instrument calibration, by fitting an atmospheric model to the observations.

(d) To compare the calibration obtained from the model to that made using the laboratory source.

(e) To derive the average and instantaneous atmospheric extinction coefficients from these measurements.

(f) To compare measured quantities such as atmospheric beam transmittance with similar measurements made in the Northern Hemisphere.

(g) To use our measured results as an approximate means of correcting LANDSAT digital data.

#### 4.3 RADIOMETER CALIBRATION

The spectral responsivity (3.1 APPENDIX) of an "ideal" LANDSAT MSS radiometer would be uniformly high within each of the 100 nm or 300 nm passbands, and zero outside the "cut off" wavelengths. The actual relative spectral responsivities of the Gamma Scientific radiometer are shown in Chapter 3, Fig. 3.8.

Using the notation and definitions of 3.1 APPENDIX, we assume that the spectral irradiance at the instrument entrance aperture is  $E(\lambda)$ , and this may be due to a source such as the sun or a calibration lamp. The relative spectral responsivity of the instrument is given by  $r(\lambda)$ . The instrument output will then be:-

$$S = R_E(\lambda_m) \int_0^{\infty} E(\lambda) \cdot r(\lambda) \cdot d\lambda \quad \dots 4.1$$

$R_E(\lambda_m)$  = the peak normalised irradiance responsivity  
[S.W<sup>-1</sup>.cm<sup>2</sup>]

$S$  = instrument output in generalised units [S]  
(which may for instance be volts or amps)

The output is therefore a function of the spectral distribution of the source, as in the case of the measurement of target radiance (3.1.2.3).

The Gamma Scientific radiometer uses a cosine receptor attachment for the measurement of irradiance. Using this receptor, the instrument spectral responsivities in each MSS band were first determined by laboratory measurements with a double prism monochromator, quartz iodine source and calibration thermopile. In Chapter 3, Fig. 3.8, we show the relative spectral responsivities of the instrument. It is seen that a "spectral leak" exists on the long-wave side of MSS band 4, and the energy contribution due to this leak amounts to 5.8% of the instrument output when viewing the calibration lamp.

The instrument absolute calibration was then found by viewing a calibration lamp of known output, that is, whose spectral irradiance at a predetermined distance from the source is known and listed. The lamp itself was checked by measuring its total output over all wavelengths and comparing this with the output of a "sub-standard" source calibrated at the National Physical Laboratory, U.K. The two values were found to agree to better than 0.5%.

When the instrument is used to measure either global or solar irradiance, the required value is usually that which is bounded by the "nominal" cut-off wavelength of each MSS passband. Thus if the lower cut-off wavelength is  $\lambda_p$  and the upper cut-off wavelength is  $\lambda_Q$  we have:-

$$E = \int_{\lambda_p}^{\lambda_Q} E(\lambda) . d\lambda \quad \dots\dots 4.2$$

This would be the irradiance measured by an "ideal" radiometer with a spectral responsivity which is constant between  $\lambda_p$  and  $\lambda_Q$  and zero outside of these limits. In table 4.1, column 3, we show the irradiance due to our calibration lamp between the "nominal" MSS band limits, and also the mean solar irradiance at the top of the atmosphere between the same limits. These values have been computed using the expression 4.2, the listed spectral irradiance of the lamp and the proposed mean standard solar spectral irradiance at the top of the atmosphere, given by Thekaekara (1972).

The Gamma radiometer will respond to radiation between its own lower and upper cut-off wavelengths  $\lambda_1$  and  $\lambda_2$  in each band. The peak normalised irradiance (3.1.3.1) indicated by this instrument is derived from expression 4.1:-

$$\frac{S}{R_E(\lambda_m)} = \int_{\lambda_1}^{\lambda_2} E(\lambda) . r(\lambda) . d\lambda \quad \dots\dots 4.3$$

This is the "effective" irradiance at the instrument aperture. The peak normalised irradiance due to our calibration lamp and for the sun at the top of the atmosphere is shown in Table 4.1, column 4.

We can also calculate the peak normalised bandwidth of each radiometer passband. The lower and upper wavelengths which define the peak normalised bandwidth are given by  $\lambda_A$  and  $\lambda_B$ , and the bandwidths for the Gamma radiometer are given in Table 4.1, column 5.

The ability of our "real" radiometer to measure the irradiances given by expression 4.2 can now be judged if we multiply the peak normalised irradiance of column 3 by the ratio of nominal to peak normalised bandwidths.

Thus:-

$$\text{Bandwidth corrected irradiance} = \frac{(\lambda_Q - \lambda_P)}{(\lambda_B - \lambda_A)} \cdot R(\lambda_m) \cdot \int_{\lambda_1}^{\lambda_2} E(\lambda) \cdot r(\lambda) \cdot d\lambda \dots 4.4$$

The values of "bandwidth corrected irradiance" are given in Table 4.1, column 6. It is seen that the largest discrepancy occurs in MSS band 7, which has the most asymmetric spectral responsivity curve. This is in accordance with the conclusions of Chapter 3, part 1.

#### 4.4 THE ATMOSPHERIC MODEL

The irradiance on a horizontal surface at ground level is termed global irradiance (3.1 APPENDIX). For a terrestrial target the global spectral irradiance is given to a good approximation by:-

$$E_G(\lambda) = E_0(\lambda) \cdot \cos Z \cdot \exp(-\alpha(\lambda) \cdot m) + E_{\text{SKY}}(\lambda) \dots 4.5$$

$E_0(\lambda)$  = solar spectral irradiance at the top of the atmosphere

$Z$  = solar zenith angle

$\alpha(\lambda)$  = atmospheric extinction coefficient at wavelength  $\lambda$

$m$  = airmass - (See 4.5).

$E_{\text{SKY}}(\lambda)$  = global spectral irradiance due to the sky only.

Equation 4.5 is based on a model which assumes that the atmosphere is layered and the layers are homogeneous. It is only valid over a limited range of zenith angles (section 4.5). It is assumed that  $m$  is not wavelength dependent. The global irradiance  $E_G$  is measured by the radiometer using a horizontally mounted Lambertian receiving surface (cosine receptor).  $E_G$  is bandwidth dependent, and the indicated value will depend on the type of normalisation employed.

Solar irradiance  $E_S$  is defined in Chapter 3 as the irradiance intercepted by a detector with its surface normal to the sun's rays and with a narrow field of view which excludes sky radiation.

Equation 4.5 then reduces to:-

$$E_S(\lambda) = E_0(\lambda) \cdot \exp(-\alpha(\lambda) \cdot m) \dots 4.6$$

$$\text{and } E_S = E_0 \cdot \exp(-\alpha \cdot m) \dots 4.7$$

$E_S$ ,  $E_0$  and  $\alpha$  are all dependent on a specified bandwidth  $\Delta\lambda$ .

For zenith angles which do not exceed a given limit (section 4.5), the airmass is approximately given by:-

$$m = \sec Z \quad \dots\dots 4.8$$

Inserting this into 4.7, we have:-

$$E_S = E_0 \cdot \exp(-\alpha \cdot \sec Z) \quad \dots\dots 4.9$$

Taking the logarithm of both sides:-

$$\ln(E_S) = \ln(E_0) - \alpha \cdot \sec Z \quad \dots\dots 4.10$$

If a series of measurements of  $E_S$  are made for different zenith angles, that is at different times during a single day, then  $\ln(E_S)$  can be plotted as a function of  $\sec Z$ , and a straight line fit to this data gives  $\alpha$  (slope) and  $\ln(E_0)$  (intercept on the  $\ln$  irradiance axis).

This method of deriving  $\alpha$  and  $E_0$  is well known, and is used by a number of authors (Shaw et al. 1973, Rogers 1974). Indeed it is the basis of the "Smithsonian long method" of determining the solar constant (Johnson 1954).

We have chosen to insert our values of  $E_S$ , measured during the course of a cloud-free day, into a computer program which performs a "least squares fit" of expression 4.9 to this data. The zenith angle corresponding to each value of  $E_S$  is computed from the time and date of measurement, observer's latitude and sun declination. Fig 4.1 is an example of measured solar irradiance  $E_S$  plotted against local time and with the solid line representing the computer fitted curve.

The measurements are made with a collimating tube fitted over the cosine receptor to exclude skylight, and with the instrument manually aligned to view the sun. The mean values of extinction coefficient and  $E_0$  are generated by the computer fit of 4.9 to the data. Note that the extinction coefficient  $\alpha$  depends only on the shape of the curve given by 4.9, and not on the absolute calibration of the instrument.

#### 4.5 THE EFFECT OF LARGE ZENITH ANGLES

The range of zenith angles which are considered to satisfy equation 4.8 varies widely with author:

| <u>Limiting range of Z</u> | <u>Author</u>     |
|----------------------------|-------------------|
| 0° - 62°                   | (Thekaekara 1972) |
| 0° - 80°                   | (Shaw et al 1973) |
| 0° - 60°                   | (Rogers 1974)     |
| 0° - 70°                   | (Johnson 1954)    |

A more accurate expression for  $m$  than in equation 4.8 is given by the empirical relation due to Bemporad:-

$$m = \sec Z - 0.001867(\sec Z - 1) - 0.002875(\sec Z - 1)^2 + 0.0008083(\sec Z - 1)^3 \quad \dots 4.11$$

The atmospheric transmission factor along the observer's line of sight is given by:-

$$\tau_S = \exp(-\alpha \cdot m) \quad \dots 4.12$$

Generally, it is the error in  $\tau_S$ , caused by an error in estimating  $m$ , which is of interest and this error is also a function of the extinction coefficient. Fig. 4.2 is a plot of  $\tau_S$  against  $m$  for various values of  $\alpha$ .  $m$  is calculated from 4.8 and 4.11. It is seen that for all values of extinction coefficient,  $\tau_S$  differs by less than 0.5% for the two values of  $m$  if the zenith angle does not exceed  $75^\circ$ .

Shaw et al (1973) and Rogers (1974) make irradiance measurements out to zenith angles of  $84.2^\circ$  ( $m = 10$ ) and  $81.7^\circ$  ( $m = 7$ ) respectively. The difficulty of making accurate measurements at these large zenith angles can be appreciated when it is realised that the airmass changes from 7 to 10 for a sun angle change of only  $2.5^\circ$ , corresponding to a change in time of ten minutes.

Because of the necessity for stability of atmospheric transmission during the determination of  $E_0$  and  $\alpha$ , we have avoided the ends of the day and limited our measurements to a period of six hours centered on solar noon, and to values of airmass not exceeding four.

#### 4.6 ESTIMATION OF $E_0$ AND $\alpha$ FROM SOLAR IRRADIANCE MEASUREMENTS

For accurate measurement of solar irradiance at the top of the atmosphere, the atmospheric conditions must be stable during the measuring period of up to six hours. This reduces the standard deviation between the measured data and the least squares fit of equation 4.9. In practice, stable conditions have occurred only infrequently. Of the New Zealand test sites at Wellington, Pauatahanui, Wainuiomata and Darfield, and the Australian site at Menindee, only three sites have yielded results with sufficiently low standard deviations. These are Wellington, Pauatahanui and Menindee.

Global and solar irradiances have been measured at about twenty minute intervals during the day. In Fig. 4.3, we show a sample of the computer output for the least squares fit of equation 4.9 to data obtained at Menindee. The first table gives measured times and irradiances, the second gives the irradiances derived from equation 4.9.  $\alpha$  is listed as "the attenuation constant"

and  $E_0$  as "solar irradiance I". The units of irradiance are those of the instrument scale reading, and require to be multiplied by our laboratory calibration coefficient to give irradiance in  $W.cm^{-2}$ . In this example, the standard deviation is seen to be 0.4% of the noon irradiance.

All our measurements have been subjected to this least squares fitting process, but only five sets of data from the three listed test sites have had sufficiently low standard deviations to be used in our estimation of  $E_0$ . The standard deviations of these data sets do not exceed 1.5% of the noon irradiances. In column 3 of table 4.2, we show the estimated values of  $E_0$  for each data set. These are the peak normalised irradiances as defined in equation 4.3. The mean values of  $\alpha$  for each MSS band, also derived from the fit of equation 4.9, are listed in column 2.

#### 4.7 ANNUAL VARIATION OF SOLAR IRRADIANCE AT THE TOP OF THE ATMOSPHERE

The published figures for  $E_0$  (Thekaekara 1972) are the mean yearly values. Before we can compare our derived values of  $E_0$ , obtained at different times of the year, with the published values, we must first correct the published values for ellipticity of the Earth's orbit.

The Earth/Sun distance at any time of the year can be computed to sufficient accuracy and as a fraction of the mean value, by an iterative procedure involving a simple form of Kepler's equation:-

$$E - e \sin E = 2\pi(t-T) \quad \dots 4.13$$

$$\text{and } r/r(\text{mean}) = 1 - e \cos E \quad \dots 4.14$$

$E$  = eccentric anomaly

$e$  = orbit eccentricity

$(t-T)$  = time after perihelion in years.

The ratio of irradiance  $E_0$  at time  $(t-T)$  to the mean value is given by:

$$E_0 = E_0(\text{mean}) \left\{ \frac{r(\text{mean})}{r} \right\}^2 \quad \dots 4.15$$

The maximum deviations from the mean occur at the perihelion (solar constant =  $1399 W/m^2$ ) and at the aphelion (solar constant =  $1309 W/m^2$ ) in accordance with the values cited by Thekaekara (1972). Column 4 of Table 4.2 shows the values of  $E_0$ .

2-2



corresponding to the dates of measurement, and calculated from the published data. These are the peak normalised values of equation 4.3, and have been produced by multiplying the tabulated spectral responsivities of the instrument with the published spectral irradiance of the sun outside the atmosphere and finding the integral under the resulting curve. They can thus be compared directly with the derived values of  $E_0$  in column 3.

#### 4.8 DIURNAL VARIATION OF EXTINCTION COEFFICIENT

In sections 4.6 and 4.7 we have checked the calibration coefficient of the radiometer (peak normalised irradiance responsivity) by comparing its value derived in two separate ways. The confidence gained from this exercise has enabled us to demonstrate the variations of extinction coefficient that can occur during a single day at three different test sites.

Fig. 4.4 shows the extinction coefficients for each MSS band plotted against local time for two sites in New Zealand, and Fig. 4.5 gives similar results for the Australian site.

#### 4.9 COMPARISON OF BEAM TRANSMITTANCE MEASUREMENTS IN THE SOUTHERN AND NORTHERN HEMISPHERE

Beam transmittance  $T_B$  is defined as the transmittance of a vertical column between the Earth's surface and the top of the atmosphere. We define  $T_B$  as:-

$$T_B = \exp(-\alpha)$$

Rogers (1974) gives average, maximum and minimum values of  $T_B$  derived from ten sets of field measurements in the eastern U.S.A. and these are reproduced in Table 4.3(c). Table 4.3(a) gives the same parameters for three sets of New Zealand data and 4.3(b) shows three sets of Australian data.

#### 4.10 SUMMARY AND CONCLUSIONS

In this paper, we have described a series of measurements of solar irradiance and atmospheric extinction coefficient, using a LANDSAT MSS radiometer with a cosine receptor and collimating tube. The signal-to-noise ratio and stability of the instrument are high enough to ensure that the recorded fluctuations in signal output (Figs. 4.1 and 4.3) and of measured extinction coefficients (Figs. 4.4 and 4.5) are due to atmospheric effects alone.

The relative spectral responsivities of the instrument MSS bands have been carefully measured in the laboratory, and a "standard" lamp has been used to obtain a calibration coefficient which converts instrument output into peak normalised irradiance.

In Table 4.2 we have listed the peak normalised irradiances due to the sun at the top of the atmosphere. One set of irradiance values are derived from the test site measurements with the laboratory calibrated instrument. The other set are calculated from the published figures of extra-terrestrial solar irradiance. The five measured and calculated sets of data are averaged, and it is found that the measured values differ from the calculated ones by the following amounts (expressed as a percentage):

|                    |                    |
|--------------------|--------------------|
| MSS band 4 : -9.4% | MSS band 5 : +6.4% |
| MSS band 6 : +0.4% | MSS band 7 : -4.6% |

In view of the large number of variables involved in these measurements we feel that this shows a good agreement between two independent forms of instrument calibration. The errors can in part be explained by the variability of the atmospheric transmission over the test sites, which accounts for the standard deviation between the measured data and the computer fitted curve. This points to the need to make more "clear day" measurements and is an argument in favour of setting up a recording radiometer which tracks the Sun and provides near-continuous data during the course of the day.

The results of the individual atmospheric extinction measurements, illustrated in Figs. 4.4 and 4.5, show clearly the greater opacity of the atmosphere in MSS band 4 which is due to Rayleigh scattering. Atmospheric water vapour absorbs strongly in a wide region between 900 nm and 1000 nm, and this results in a consistently higher extinction coefficient than would otherwise be expected in MSS band 7. The short term fluctuations tend to be greater in band 7 than in the other bands, and this effect is probably due to variations of water vapour concentration in the instrument line of sight. These high extinction coefficients and short term fluctuations in band 7 have been observed at Menindee (Fig. 4.5) which is in a semi-desert region in western New South Wales. The measurements were made in very hot conditions near an irrigation lake and canal. Calculations of atmospheric path length and water vapour concentrations required to produce these effects would need to be made before they could be attributed to "local" near ground conditions, or to events higher in the atmosphere.

A comparison of the beam transmittance measurements of Rogers (Table 4.3) with the New Zealand and Australian values shows some interesting features, although many more measurements would need to be made before they assumed a statistical significance. These results show a consistently higher atmospheric transmittance at the New Zealand and Australian test sites for the two visible and the first IR spectral bands, and a reduced transmittance for MSS band 7, when compared to the Northern Hemisphere values.

It is anticipated that atmospheric measurements will continue in New Zealand along the lines discussed in this paper. In future we intend to use a spectrometer to measure solar spectral irradiance, and to investigate the relationships between our solar and global irradiance measurements.

#### 4.11 REFERENCES

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| Source | Instrument Reading | Irradiance Within Nominal MSS Bands<br>$\mu\text{W.cm}^{-2}$ | Measured Peak Normalised Irradiance<br>$\mu\text{W.cm}^{-2}$ | Radiometer Peak Normalised Bandwidth<br>nm | Measured Bandwidth Corrected Irradiance<br>$\mu\text{W.cm}^{-2}$ | MSS CH. NO. |
|--------|--------------------|--------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------|------------------------------------------------------------------|-------------|
| S1     | 20.6               | 503                                                          | 366                                                          | 72.8                                       | 503                                                              | 4           |
| "      | 37.8               | 912                                                          | 985                                                          | 104.5                                      | 943                                                              | 5           |
| "      | 57.3               | 1194                                                         | 1487                                                         | 124.4                                      | 1195                                                             | 6           |
| "      | 85.1               | 4075                                                         | 3539                                                         | 264.6                                      | 4012                                                             | 7           |
| S2     |                    | 17700                                                        | 12820                                                        | 72.8                                       | 17700                                                            | 4           |
| "      |                    | 15150                                                        | 15570                                                        | 104.5                                      | 14900                                                            | 5           |
| "      |                    | 12370                                                        | 15340                                                        | 124.4                                      | 12330                                                            | 6           |
| "      |                    | 24910                                                        | 24220                                                        | 264.6                                      | 28240                                                            | 7           |

Notes: 1 - Source S1: Calibration lamp No. 178A at 2854°K

2 - Source S2: Mean solar irradiance at top of atmosphere

3 - Definitions of terms in Chapter 3.1 APPENDIX

TABLE 4.1

Measured and calculated irradiances in the MSS spectral bands, due to a calibration lamp and to the mean solar flux at the top of the atmosphere.

| Test Site<br>Location - Date             | Extinction<br>Coefficient $\alpha$ | Measured<br>Value of $E_0$<br>$\mu\text{W}/\text{cm}^2$ | $E_0$ from<br>Published Data<br>$\mu\text{W}/\text{cm}^2$ | MSS<br>Channel<br>Number |
|------------------------------------------|------------------------------------|---------------------------------------------------------|-----------------------------------------------------------|--------------------------|
| Menindee -<br>Lake Tandou<br>23 Nov 1975 | 0.130                              | 11570                                                   | 13161                                                     | 4                        |
|                                          | 0.120                              | 17156                                                   | 15990                                                     | 5                        |
|                                          | 0.055                              | 15201                                                   | 15775                                                     | 6                        |
|                                          | *                                  | *                                                       | *                                                         | 7                        |
| Menindee -<br>Lake Tandou<br>24 Nov 1975 | 0.158                              | 11803                                                   | 13166                                                     | 4                        |
|                                          | 0.103                              | 16619                                                   | 15996                                                     | 5                        |
|                                          | 0.093                              | 15559                                                   | 15762                                                     | 6                        |
|                                          | 0.143                              | 23544                                                   | 24884                                                     | 7                        |
| Menindee -<br>Lake Tandou<br>25 Nov 1975 | 0.179                              | 11974                                                   | 13170                                                     | 4                        |
|                                          | 0.126                              | 16882                                                   | 16002                                                     | 5                        |
|                                          | 0.135                              | 16249                                                   | 15766                                                     | 6                        |
|                                          | *                                  | *                                                       | *                                                         | 7                        |
| Wellington<br>P.E.L.<br>23 July 1975     | 0.175                              | 11304                                                   | 12424                                                     | 4                        |
|                                          | 0.114                              | 15995                                                   | 15095                                                     | 5                        |
|                                          | 0.081                              | 14788                                                   | 14874                                                     | 6                        |
|                                          | 0.093                              | 22429                                                   | 23482                                                     | 7                        |
| Pauatahanui<br>Boat House<br>9 Feb 1977  | 0.182                              | 12354                                                   | 13147                                                     | 4                        |
|                                          | 0.117                              | 17447                                                   | 15973                                                     | 5                        |
|                                          | 0.112                              | 16449                                                   | 15739                                                     | 6                        |
|                                          | 0.122                              | 23927                                                   | 24848                                                     | 7                        |
|                                          | Average<br>Values<br>of $E_0$      | ( 11801<br>( 16820<br>( 15649<br>( 23300                | 13014<br>15811<br>15583<br>24405                          | 4<br>5<br>6<br>7         |

Table 4.2 .

Values of extinction coefficient and  $E_0$  derived for computer fit of Equation 2.3.3, compared to  $E_0$  obtained from published data (Thekaekara 1972)

\* Standard deviation too large in these channels.

| MSS Band | Average | Maximum | Minimum | Standard Deviation |
|----------|---------|---------|---------|--------------------|
| 4        | 0.853   | 0.867   | 0.827   | 0.010              |
| 5        | 0.903   | 0.915   | 0.883   | 0.009              |
| 6        | 0.920   | 0.934   | 0.895   | 0.007              |
| 7        | 0.896   | 0.915   | 0.829   | 0.016              |

(a) Compiled from three ( WELLINGTON 23 July 1975  
sets of data at New ( DARFIELD 3 Aug 1975  
Zealand test sites ( PAUATAHANUI 9 Feb 1977

| MSS Band | Average | Maximum | Minimum | Standard Deviation |
|----------|---------|---------|---------|--------------------|
| 4        | 0.845   | 0.860   | 0.831   | 0.007              |
| 5        | 0.884   | 0.899   | 0.860   | 0.009              |
| 6        | 0.901   | 0.920   | 0.880   | 0.010              |
| 7        | 0.866   | 0.903   | 0.807   | 0.018              |

(b) Compiled from three ( MENINDEE 21 Nov 1975  
sets of data at an ( " 24 Nov 1975  
Australian test site ( " 25 Nov 1975

| MSS Band | Average | Maximum | Minimum | Standard Deviation |
|----------|---------|---------|---------|--------------------|
| 4        | 0.799   | 0.856   | 0.697   | 0.051              |
| 5        | 0.852   | 0.901   | 0.770   | 0.048              |
| 6        | 0.885   | 0.940   | 0.812   | 0.051              |
| 7        | 0.899   | 0.975   | 0.843   | 0.052              |

(c) Compiled from 10 sets of data in Eastern USA test site over the period January-June 1973 (Rogers 1974).

Table 4.3

Comparison of Beam Transmittance Measurements in Southern and Northern Hemisphere.

# IRRADIANCE MEASUREMENTS

WELLINGTON, N.Z.

23<sup>rd</sup> JULY, 1975.

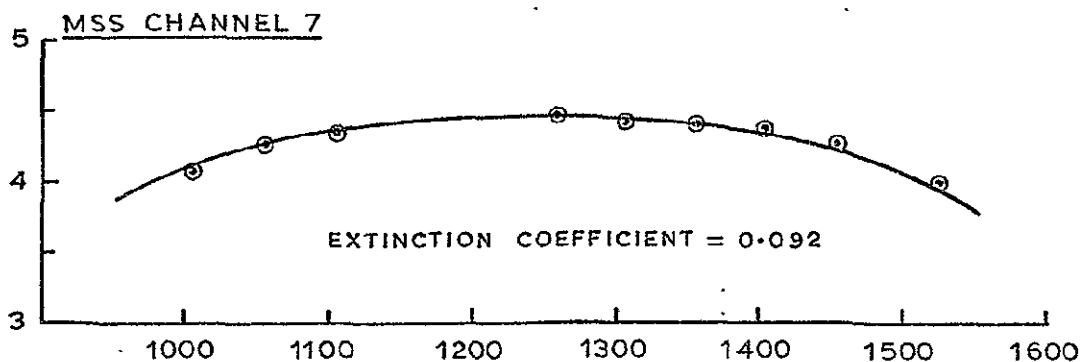
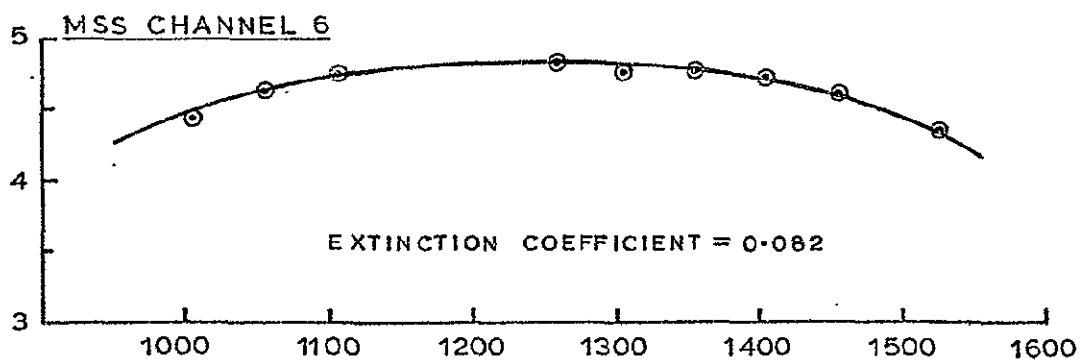
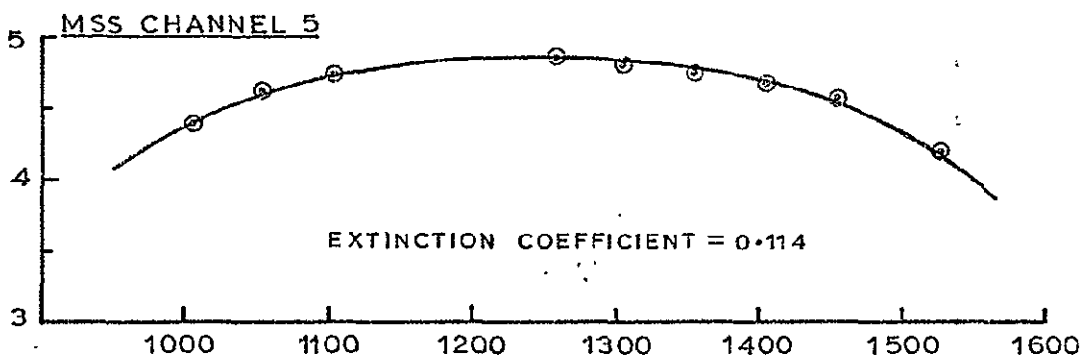
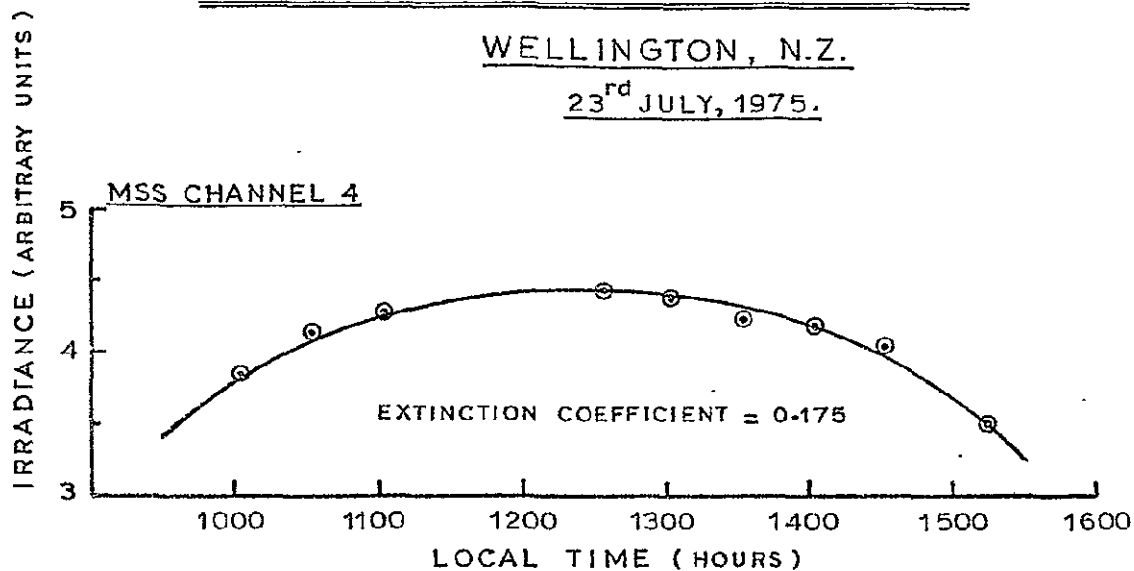


FIG. 4.1

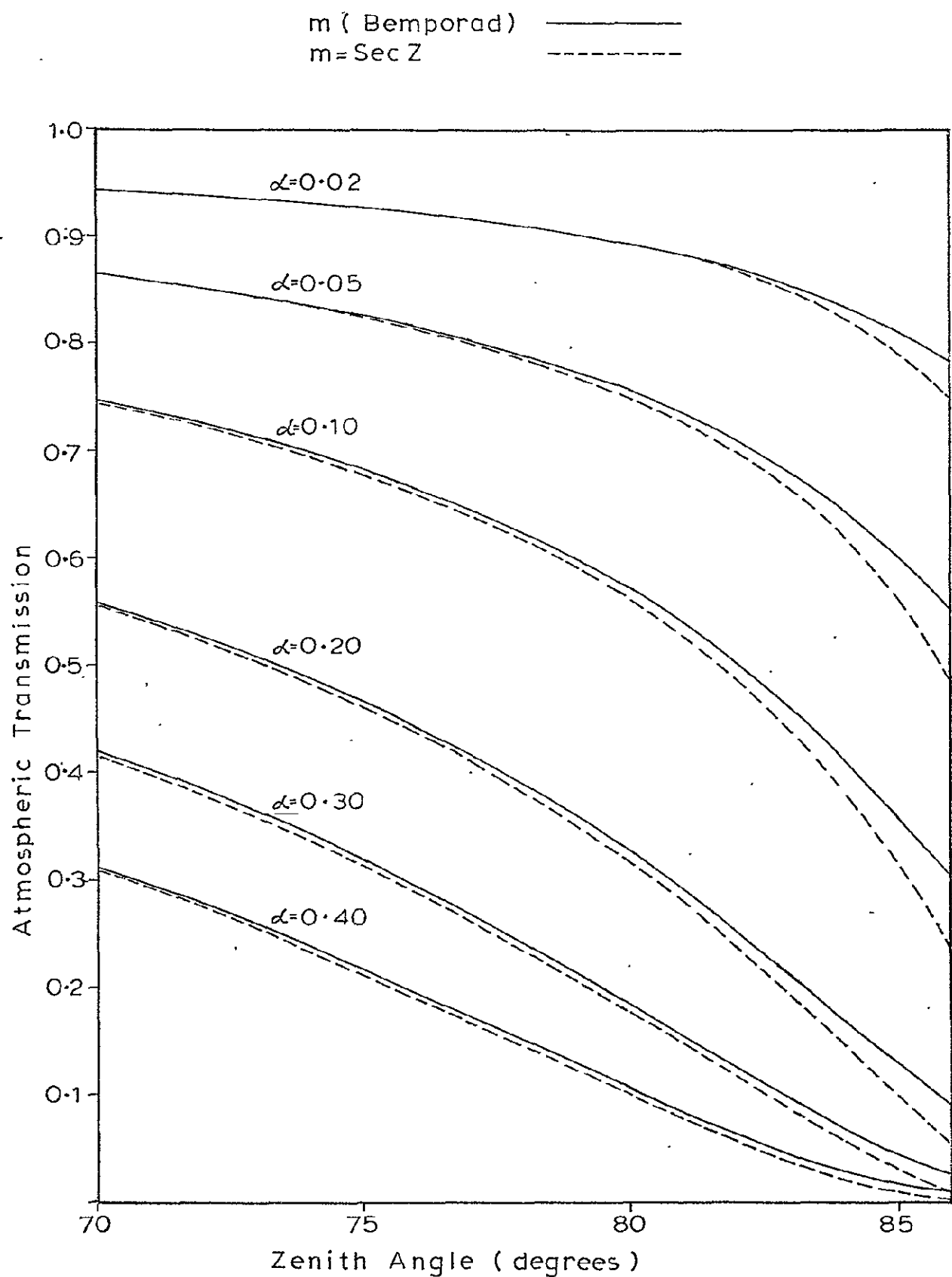


FIG. 4.2      Plot of Atmospheric Transmission against Zenith Angle for Different Values of Extinction Coefficient  $\alpha$



MENINDEE - LAKE TANDOU--\*\*\*\*--24 NOVEMBER 1975  
MSS CHANNEL NO. 1

# MEASURED TIMES AND VALUES

\*\*\*\*\*

| LOCAL<br>TIME<br>HOURS | ZENITH<br>ANGLE<br>DEGREES | AIRMASS<br>SEC Z | LOG<br>IRRADIANCE | IRRADIANCE |
|------------------------|----------------------------|------------------|-------------------|------------|
| 9.26667                | 54.8078                    | 1.73514          | 3.91801           | 50.3       |
| 9.68333                | 49.547                     | 1.54125          | 3.95124           | 52         |
| 9.95                   | 46.1794                    | 1.44425          | 3.9634            | 52.9       |
| 10.25                  | 42.398                     | 1.35413          | 3.97968           | 53.5       |
| 10.5                   | 39.2588                    | 1.2915           | 3.99083           | 54.1       |
| 10.7333                | 35.7234                    | 1.23176          | 4.03186           | 54.7       |
| 11.1                   | 31.8154                    | 1.17683          | 4.01277           | 55.3       |
| 11.5667                | 26.2023                    | 1.11453          | 4.02356           | 55.9       |
| 11.8333                | 23.1224                    | 1.08735          | 4.02714           | 56.1       |
| 12.25                  | 18.6401                    | 1.05536          | 4.03424           | 56.5       |
| 12.5167                | 16.1238                    | 1.04095          | 4.03424           | 56.5       |
| 12.9167                | 13.2777                    | 1.02747          | 4.03069           | 56.3       |
| 13.1667                | 12.3709                    | 1.02377          | 4.02356           | 55.9       |
| 13.65                  | 13.0954                    | 1.0267           | 4.02714           | 56.1       |
| 14.2167                | 17.305                     | 1.04741          | 4.02892           | 56.2       |

\*\*\*\*\*

NUMBER OF ITERATIONS = 12  
THE ATTENUATION CONSTANT IS .158599  
SOLAR IRRADIANCE I IS 66.4144

THESE ARE THE TABULATED VALUES OF  $I \exp(-J/G(T))$

| LOCAL<br>TIME<br>HOURS | ZENITH<br>ANGLE<br>DEGREES | AIRMASS<br>SEC Z | LOG<br>IRRADIANCE | IRRADIANCE |
|------------------------|----------------------------|------------------|-------------------|------------|
| 8                      | 70.6441                    | 3.01717          | 3.71739           | 41.157     |
| 8.5                    | 64.4359                    | 2.31738          | 3.82838           | 45.938     |
| 9                      | 58.1674                    | 1.89595          | 3.89522           | 49.1668    |
| 9.5                    | 51.8627                    | 1.61931          | 3.93909           | 51.372     |
| 10                     | 45.5485                    | 1.42795          | 3.96944           | 52.955     |
| 10.5                   | 39.2588                    | 1.2915           | 3.99108           | 54.1135    |
| 11                     | 33.0438                    | 1.19296          | 4.00671           | 54.9659    |
| 11.5                   | 26.9902                    | 1.12223          | 4.01793           | 55.5859    |
| 12                     | 21.2696                    | 1.0731           | 4.02572           | 56.0208    |
| 12.5                   | 16.2697                    | 1.04172          | 4.0307            | 56.3002    |
| 13                     | 12.8864                    | 1.02584          | 4.03322           | 56.4422    |
| 13.5                   | 12.5226                    | 1.02437          | 4.03345           | 56.4554    |
| 14                     | 15.3948                    | 1.03722          | 4.03141           | 56.3404    |
| 14.5                   | 20.1578                    | 1.06525          | 4.02697           | 56.0905    |
| 15                     | 25.7724                    | 1.11046          | 4.0198            | 55.6898    |
| 15.5                   | 31.7756                    | 1.17631          | 4.00935           | 55.1112    |
| 16                     | 37.9661                    | 1.26843          | 3.99474           | 54.3118    |
| 16.5                   | 44.2453                    | 1.39595          | 3.97452           | 53.2245    |
| 17                     | 50.5576                    | 1.57405          | 3.94627           | 51.7421    |
| 17.5                   | 56.8666                    | 1.82952          | 3.90575           | 49.6875    |

EXPECTED (COMPUTED) NOON VALUE = 56.4653  
STANDARD DEVIATION = .225519

Figure 4.3

Sample output from least squares fit of  
equation 4.6 to measured data.

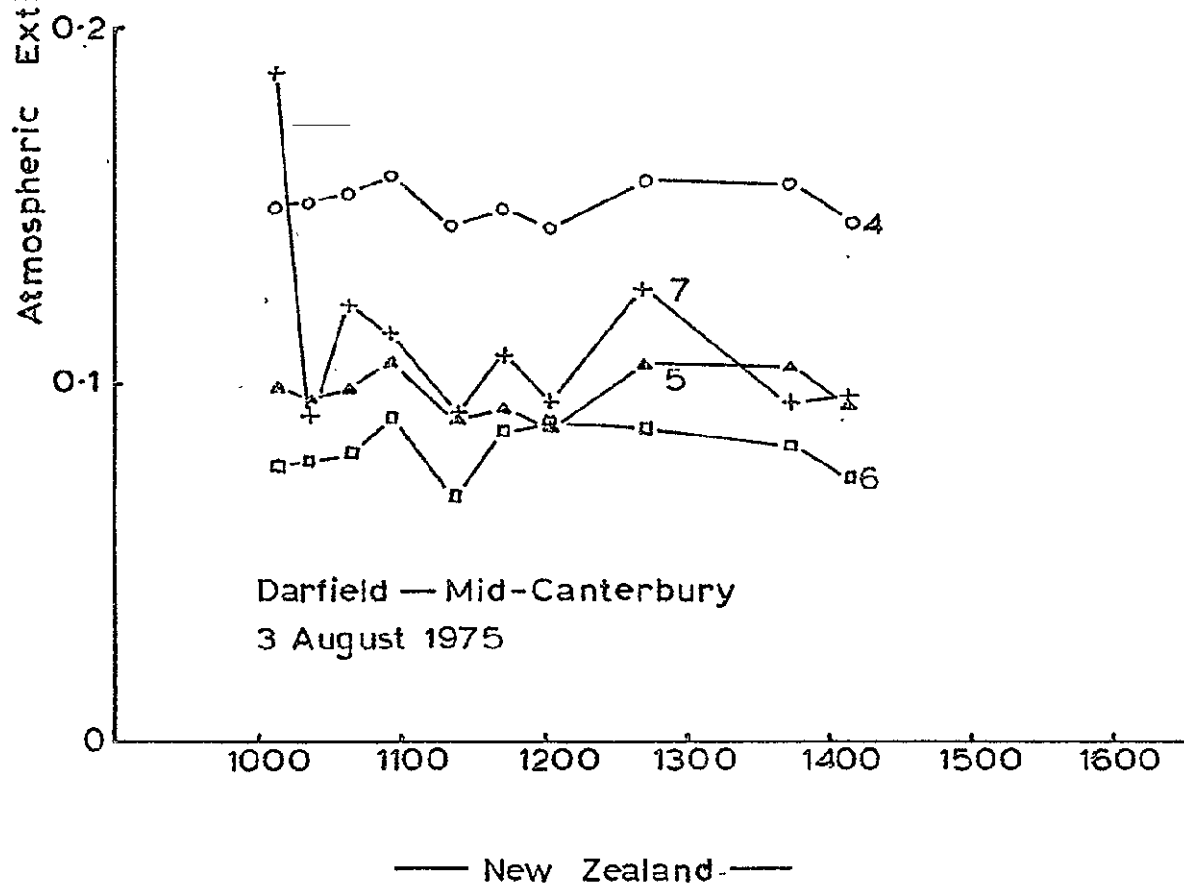
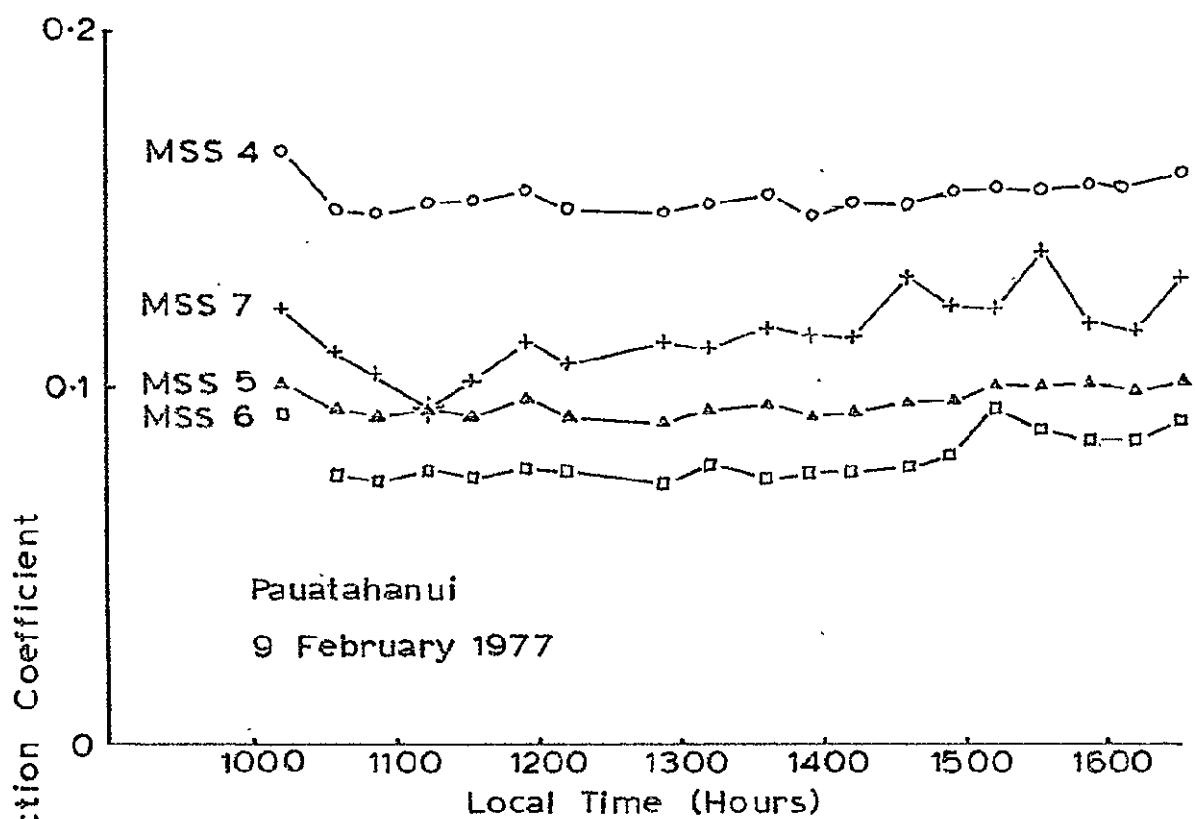


Fig. 4.4 Variation of Atmospheric Extinction Coefficient

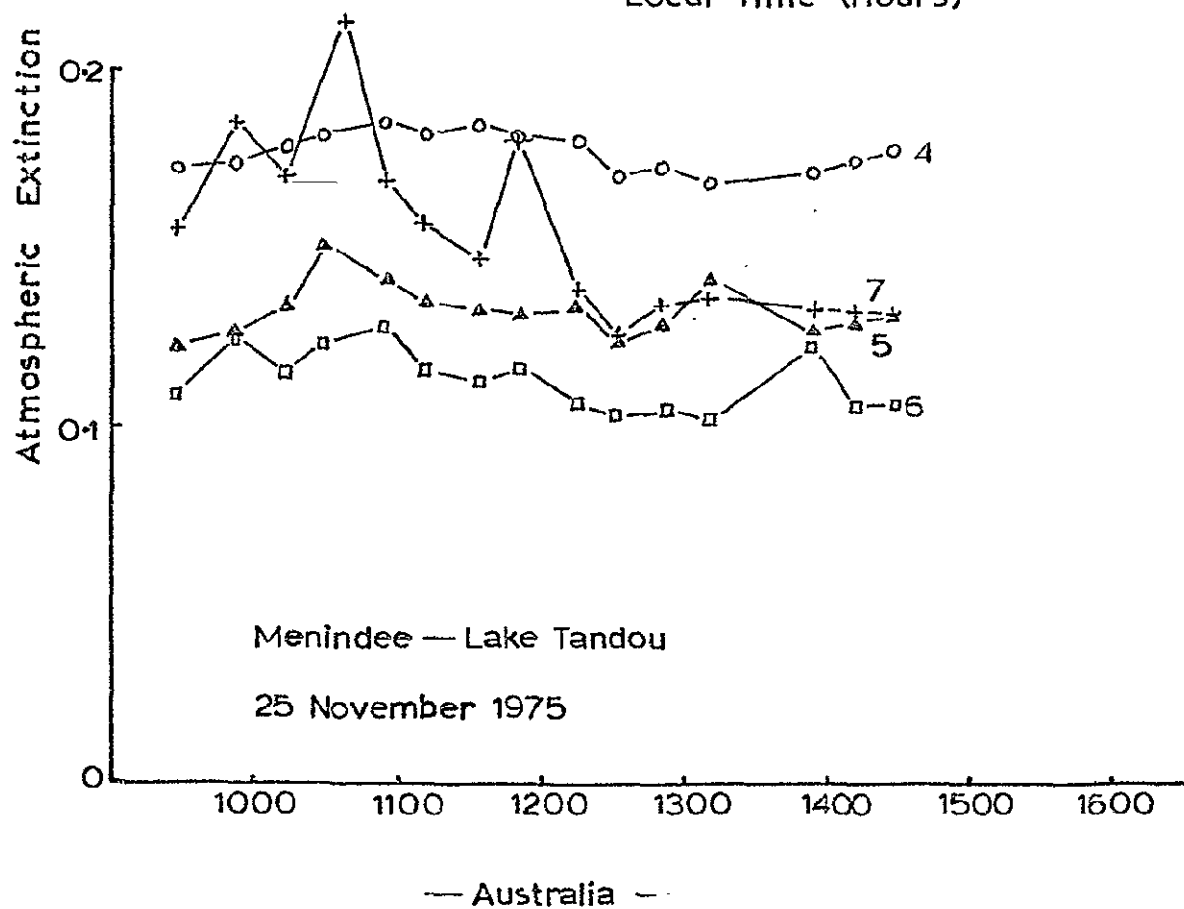
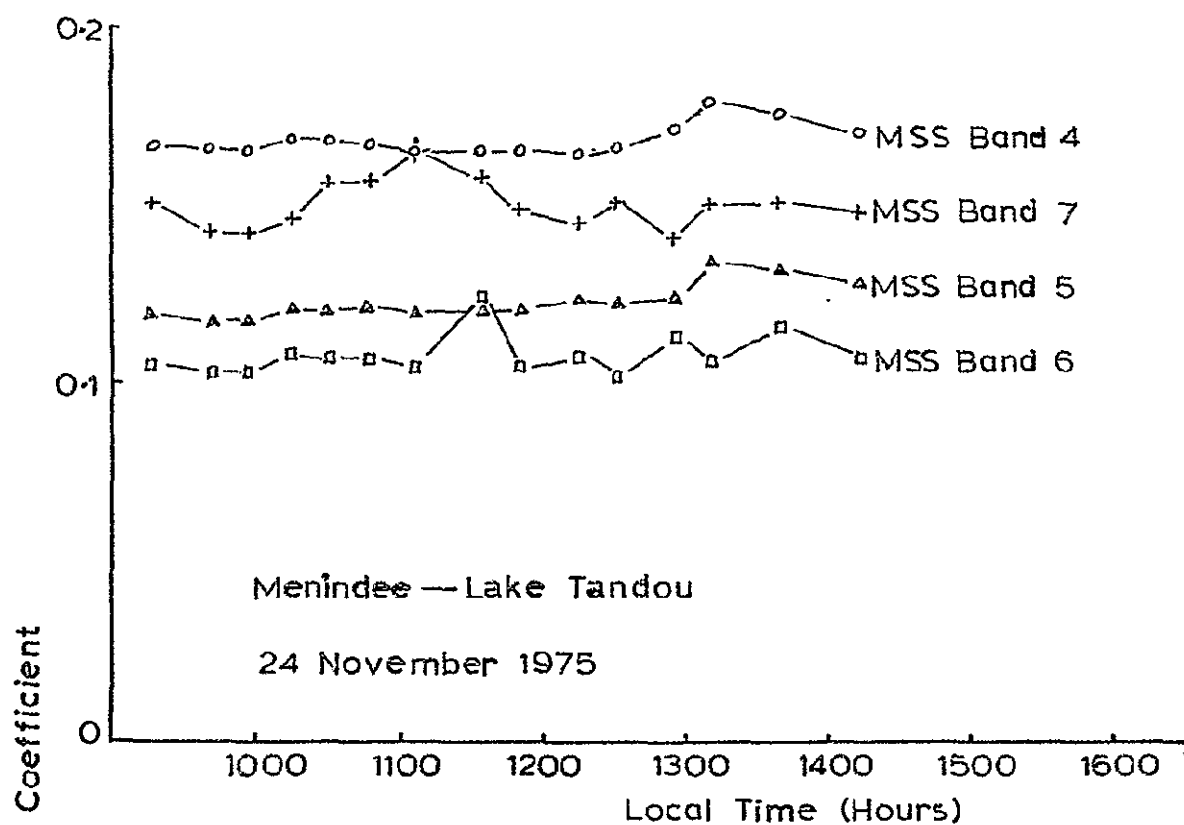


Figure. 4.5 Variation of Atmospheric Extinction Coefficient

## CHAPTER 5

## PHOTOGRAPHIC PROCESSING OF LANDSAT AND AIRCRAFT IMAGERY

A. D. Fowler, P. J. Ellis, R. C. Child  
and C. Nankivell

ABSTRACT

This paper describes the development of a photographic processing laboratory for the production of colour composites and enhanced imagery from Landsat and aircraft multispectral transparencies. These products are distributed to all New Zealand participants in the Landsat II Investigation Programme. Particular attention is given to the problem of achieving adequate image registration during the colour compositing process.

## CHAPTER 5

## PHOTOGRAPHIC PROCESSING OF LANDSAT AND AIRCRAFT IMAGERY

A. D. Fowler, P. J. Ellis, R. C. Child  
and C. Nankivell

### 5.1 INTRODUCTION

When the remote sensing section was first formed, a decision was made to develop a photographic processing laboratory. The justification for this included the need to develop new techniques, for instance in making colour composites, that were not available elsewhere in New Zealand. Also, the section had an obligation to produce imagery for the Co-investigators and other users, in the form most suitable for their interpretation. The retrospective view shows that this decision was a sound one, and has formed the base from which all our subsequent work has grown.

In this chapter, we briefly describe the facilities and photographic processing techniques that are now available. Many man-hours have been devoted to solving problems during the development stages, and of these the problem of image registration in colour-composite production has probably been the most difficult. We therefore repeat the section on image registration analysis first published in our second quarterly report to NASA, together with more recent work in which the computer is used to predict and minimise registration errors.

We report on a technique which is new to our program, and which is particularly interesting because of its great simplicity and potential value. This consists of projecting part of a Landsat scene through a transparent base map when printing, thus producing an accurately scaled print with mapping detail overlaid. This is described in Section 5.5

It is anticipated that the facility will be increasing its versatility in the near future when a "colorwrite" machine capable of converting digitally enhanced imagery into pictorial form, becomes operational.

### 5.2 OBJECTIVES OF PROCESSING FACILITY

Production of monochrome prints, enlargements and mosaics from Landsat 70 mm transparencies and from the PEL aircraft camera products.

Production of Landsat colour composites and enlargements for Co-investigators and other groups.

Investigation and utilisation of new colour processes.

Development of colour compositing methods and equipment.

Co-operation with the Department of Lands and Survey to make products generally available in New Zealand.

### 5.3 EQUIPMENT

The small purpose-built darkrooms are equipped with a semi-automatic film and print processor (MAF1), a colour enlarger for up to 10" x 10" transparencies (CHROMEGA), and a "Mini-Addcol" colour additive viewer (I<sup>2</sup>s). Ancillaries include a filtered temperature-controlled water supply, exposure monitoring and control instrumentation and supply voltage stabilisation.

### 5.4 PRODUCTS

#### 5.4.1 Monochrome Products

The Department of Lands and Survey has undertaken to make and distribute Landsat "quick look" print sets to users in this country, and to provide 1:1 000 000 scale monochrome prints through their Photo Library (See Part II).

The remote sensing section therefore produces only monochrome prints for NASA reports, special enlargements for users and prints of the aircraft multispectral surveys.

#### 5.4.2 Colour Products

Colour composite prints at a scale of 1:1 000 000 are made of all "good" scenes received from the EROS Data Center, that is, scenes of acceptably low cloud cover and without missing MSS bands. The prints are originally made by direct exposure on the colour additive viewer from 70 mm negatives. For prints required in numbers, or for subsequent enlargement, 70 mm positive transparencies are used to make colour internegatives from which prints and enlargements can be produced by conventional means. For analysis of small areas, portions of individual MSS bands are enlarged and then colour composited, to reduce registration problems and to enhance the dynamic range.

Aircraft 70 mm negatives are first developed to a "gamma" of 1.7 and then colour composited in the same way as the Landsat images.

The time sequential process is an alternative to the colour additive viewer as a means of making colour composites. This was first developed to avoid some of the registration problems in the viewer, but is now used for compositing "photowrite" and other transparencies which are too large to fit the Mini-Addcol. Three transparencies are initially punch registered, and then overlaid in sequence on colour negative film and exposed to red, green and blue filtered light respectively. Fig. 8.4 shows a geometrically corrected portion of a Landsat image produced in this way.

Another routinely employed technique is the "Cibachrome" process for making prints directly from positive transparencies. In this report, all scenes taken from the "Datacolor 703" density slicer and the "Image 100" analyser are produced by this method.

The colour balance in all these products can be varied to aid in the discrimination of a specific target. Our "standard" products do not reproduce the NASA "grey" scale as grey, but rather with a bias towards the blue-green to give a greater range of colour in the image. In some case, notably for the N.Z. Geological Survey, we have produced colour combinations of positive and negative transparencies to highlight topographical features.

## 5.5 LOCATION ON LANDSAT PHOTO PRODUCTS

With the photographic product of Landsat imagery being used for "eyeball" interpretation users have experienced difficulties in locating positions, especially in the more remote back country areas. Also we have found that in cases where work has been conducted on enlargements, invariably the enlargement has been "approximate" to a published map scale. We have investigated this problem and the first recommendation was that wherever possible, enlargement should be to a conventional scale enabling the use of scaling techniques and visual comparison with printed maps. In New Zealand the scales of mapping that are available covering the whole country are:- 1:1 000 000, 1:500 000, 1:250 000 and 1:63 360 with work being conducted in some areas at 1:100 000 and 1:50 000. To facilitate the identification and location of data and as a possible cartographic product we investigated combining line formation with the Landsat product.

To try to locate the position of our cartographic reflector on a recent Landsat image we projected the photographic product, enlarged to fit the line-work on a printed 1:63 360 map. As the map detail obscured the projected image we replaced the printed map by a transparency of the hydrography and base detail and fitted the projected image to this detail. Unexposed film was then arranged under the transparency without disturbing the transparency's relativity to the projected image and an exposure made.

At 1:63 360 scale the resultant print was poor but when the experiment was repeated at 1:250 000 scale with recent line information produced from photogrammetric compilation, the result was far better. The print at 1:250 000 was a positive continuous tone image with negative map information. This was achieved using 1:3 369 000 negative in the enlarger. Fig. 5.1 shows a sample of a scale print with map overlay in an agricultural area. In this area roads can only be interpreted on the photographic product with difficulty but this and field identification is greatly improved by the addition of line information.

Other applications for this technique were investigated. As a base for high country management farms the Landsat image was combined with a specially produced simplified line base. This is a cheap, simple and effective method of producing a realistic information base.

As an interpretation aid in land use mapping, by successively producing the four bands with line work of a topographic/cadastral combination it will be very useful and will be used in the investigation of two study areas of New Zealand, the King Country and the Upper Waitaki and MacKenzie basin.

Further work of combining soils, geological, homogenous unit pattern and erosion potentials will be investigated next.

Map projection problems were not very obvious at the scale of 1:250 000 if the image was kept to a reasonable size and we appreciate that as a pure cartographic product there are discrepancies, but as an interim product we have found it very useful and attractive.

## 5.6 IMAGE REGISTRATION

To avoid the need to refer to our second quarterly report to NASA (PEL No. 531), we reproduce here essentially the same analysis of the cause of registration errors due to the colour compositing process.

We have found that registration errors have two causes. The first is the geometric distortion of the project image introduced by the additive viewer, and the second is the geometric differences between bands which have occurred in the 70 mm products.

In the case of the Landsat products, these differences can be measured by using the fiducial marks as reference points. In the case of our own aircraft products, the differences are largely due to relative tilt in the film planes of the four cameras which introduces relative trapezium distortion.

The analysis is brought up to date by an account of a computer method of predicting the adjustments required in the viewer to minimise registration errors, and to indicate the magnitude of residuals which cannot be corrected.

### 5.6.1 Registration Requirements

The 70 mm photographic product utilises a scan line length (cross track) of 55 mm, with a nominal in-track image size of 53 mm. The number of picture elements (pixels) in the cross track direction is typically 3240 and in the in-track direction there are 2256 scan lines. This gives a pixel size on the negative of 0.017 mm x 0.023 mm corresponding to a ground field of view of 57 x 79 m.

It follows that there are approximately 59 pixels per mm in the cross track direction and 43 per mm in the in-track direction. The Data Users Handbook (ERTS-1) gives the modulation transfer function (MTF) for the 70 mm third generation film material; and indicates that the modulation depth has fallen to 70% of its maximum value at a spatial frequency of about 50 cycles/mm.



The film characteristics, together with the modulation transfer function of the scanner itself, will introduce "adjacency" effects between pixels, particularly in the cross track direction, which degrades the spatial resolution and reduces the necessity for precise registration to within small fractions of a pixel.

Evaluation of enlarged colour composites has indicated that registration errors are detectable on the image if the misalignment exceeds about 0.02 mm on the transparency. This is most easily apparent as colour fringing at the fiducial marks, which have a measured line width of 0.05 mm.

#### 5.6.2 Error Investigation and Alignment of the Colour Additive Viewer

Experiments with duplicated images of a test grid showed that registration errors of up to 0.4 mm were occurring on the screen of the colour additive viewer. The schematic arrangement of the "Mini-Addcol" viewer is shown in Figure 5.2(a). Registration of the images on the viewing screen is achieved by translational adjustments of the individual projection lenses, and by rotation of the 70 mm transparencies in the carrier. The large mirror should be adjusted until the viewing screen is optically parallel to the transparency carrier. Small changes of scale are possible by screwing individual lenses along the axis normal to the transparency plane. The overall magnification is set to 3.369, giving a 1:1 000 000 scale image on the viewing screen. A vacuum back, containing colour film or print material, replaces the screen when making colour composites.

Initially, the original plate glass mirror was replaced by a much thicker, optically plane, front aluminised mirror produced in the PEL optics section. The projection lenses were also checked for distortion by this section. Tests so far show that misregistration errors due to lens distortion are negligibly small.

The major contribution to misregistration error was shown to be the incorrect alignment of the plane surfaces in the instrument. For correct operation with perfect products, it is essential that the individual transparencies are optically parallel to the viewing screen. Rotation of a transparency about an axis parallel to its plane has the effect of producing trapezium distortion in the image. The effect of rotation on the magnified image can be estimated by considering the effect on its extremities. In the case of Landsat images, these extremities can be regarded as the fiducial marks.

Let  $\theta$  = the maximum angle between the normal to the transparency plane, and an extreme ray joining a fiducial mark with the nodal point of the lens.

We assume that a small rotation of the transparency from the plane parallel position, about an axis lying in the transparency plane, produces a displacement  $\delta Z$  of the fiducial mark in the direction of the normal to the plane (Z-axis).

Then the maximum displacement  $\delta r$  of the image of the fiducial mark in the viewing plane is, to a good approximation

$$\delta r = M \delta Z \tan (\theta)$$

where  $M$  is the instrument magnification.

Taking into account the lateral displacement of the lens in the colour additive viewer, the maximum angular displacement of a fiducial mark from the Z-axis is  $17.2^\circ$ . This means that a Z displacement of that fiducial mark of 0.1 mm will result in a shift of 0.1 mm of its image in the viewing screen.

The nature of the off-axis optical system means that fiducial marks on the same image will have different angular displacements from the Z-axis.

### 5.6.3 Alignment

By angular adjustment of the mirror, it is possible to make the plane of the transparency carrier and of the viewing screen optically parallel. Great difficulty has been experienced in the past in achieving this alignment. This has now been made much easier with the small ray projector shown in the simplified diagram of Fig. 5.2(b). With the lenses removed from the viewer, the projector is mounted on the rear of the viewing screen. The transparencies are replaced with non-reflecting black paper, and the projected ray is reflected from the surfaces of the bottom glass of the transparency holder. An image of the aperture-plate is focused through a hole on the projector mount on to the viewing screen. The attitude of the projector can be adjusted by screws forming two of the three kinematic supporting feet.

If the carrier and screen are optically parallel, rotation of the projector mount will not affect the relative positions of the focused ray and the hole in the mount. By iterative adjustment of the mirror angular position and the projector attitude, it is possible to align the surfaces to a high accuracy in a short time. The total path length of the ray is 1700 mm, giving a ray displacement of 0.99 mm for a rotational error of one arc minute. This rotational error, about an image centre, corresponds to a maximum fiducial mark displacement of 0.041 mm on the viewing screen.

When first used, the projector produced two displaced images on the screen for three out of the four transparency holders. These images, displaced by as much as 2.5 mm, indicated that the front and back surfaces of the transparency holder-glass were not parallel. Subsequent measurements showed thickness variations across the glass of more than 0.05 mm. An unfavourable combination of glasses would cause apparent misregistration errors of 0.007 mm at the 1:3 369 000 scale, i.e., just over one third of a pixel. The optics section at PEL has produced a set of optically parallel replacement glasses.

The projector also showed that the four transparency holders were not plane parallel. The transparency carrier itself became slightly distorted when inserted into the machine and this alone introduces a considerable rotational error. Each transparency holder is aligned after manufacture, by adjustment of three support screws. These have now been replaced by socket head screws, enabling each holder to be individually aligned in situ. Small distortions in the transparencies themselves can also be corrected in this way (see Section 5.6.4).

The realigned system, with lenses set to give a magnification of 3.369, showed an improvement of about a factor of five over previous work. Fig. 5.4, of the central North Island region, is an example of a print produced directly on the improved system.

#### 5.6.4 Spatial Distortion of 70 mm Photographic Products

Image distortion on the 70 mm transparencies can, in certain cases, be reduced by careful alignment of the holders in the additive viewer. This does, however, increase the complexity of colour compositing considerably.

Fig. 5.3 shows the disposition of the image and fiducial marks on the Landsat II 70 mm negative. Careful measurements of four scenes have been made. The fiducial marks are intended to assist in image registration, and our experience indicates that correlation between fiducial mark registration and image registration is excellent. However, the fiducial marks depart from the positions postulated by the rectangular set given in the Data Users Handbook, and these positions vary between scenes and between bands.

The results of the four sets of measurements are given in Table 5.1. A description of the method of measurement follows. All measurements were made on a "Tri-Optic" measuring machine, manufactured by S.I.P. Geneva, and housed in the PEL Metrology section. This machine operates in a temperature and humidity controlled environment ( $20^{\circ}\text{C} \pm 1^{\circ}\text{C}$  and  $<60\% \text{ RH}$ ). Scale resolution is  $0.000\ 05''$  and interpolation can be made to  $0.000\ 01''$ . All co-ordinates refer to the centres of the fiducial marks. The negatives are mounted on an illuminated plane table, and kept flat with a cover glass previously checked for flatness and thickness variations. Repeatability of measurements has been estimated by making multiple checks of twelve fiducial mark separations, over a period of days. The rms error was found to be  $0.000\ 05''$  or  $0.0013\ \text{mm}$ .

Fig. 5.3 shows the co-ordinate system, in which all co-ordinates are referred to fiducial mark F1 as the origin, and defining the X-axis as the line passing through F1 and F4.

Examination of the data shows that the fiducial mark separation in the in-track (Y) direction is always greater than the nominal dimension of  $59.5\ \text{mm}$ , with a maximum discrepancy of  $0.874\ \text{mm}$  (1.46%), and a minimum of  $0.451\ \text{mm}$ . A check of image scale by the Department of Lands and Survey confirms that the images are elongated in proportion to the observed discrepancies.

The data also shows that the four-sided figure with corners defined by the fiducial marks is not always a rectangle. These deviations vary from band to band within the same scene. Misregistration due to these effects can sometimes be partially compensated by adjustments to each individual negative carrier plane in the additive viewer.

In the next section, we describe a method of making these adjustments.

#### 5.6.5 Minimising Errors by Viewer Adjustment

We begin by assuming that the screen of the colour additive viewer is ruled with a set of four fiducial marks, spaced to register exactly with the marks on a "perfect" 1:1 000 000 scale Landsat transparency. Now if a real image is projected on to the screen and registered using the lens translation and image rotation controls, residual errors will tend to remain for the reasons discussed in 5.6.2 to 5.6.4.

In general, the fiducial marks in the projected image will form the corners of a quadrilateral in which no two sides are parallel. If the transparency itself is elongated as in the examples of 5.6.4, then it may be sufficient to match the projected image to a rectangular set of reference marks which are elongated in the same proportion. Alternatively, it may be desired to achieve the best relative registration between the images forming the composite, to minimise "fringing" effects in the final product.

For each of these criteria there exists an "optimum" viewer adjustment which minimises the sum of the squares of the displacement errors of all four fiducial points.

We now refer to an orthogonal co-ordinate system with its origin at the screen centre, X axis horizontal, Y and Z axes as shown in Fig. 5.2(a). The Z axis is parallel to the optical axis of the system. In an otherwise perfect system, misregistration will occur if the transparency plane is not optically parallel to the screen (section 5.6.2). The trapezium distortion so produced cannot be matched in the other projected images by rotation of their transparencies about axes parallel to the X-Y axes. This is due to the "off-axis" displacement of each transparency. There is thus a unique adjustment for each composite which for a perfect system requires that all transparency planes are optically parallel to the screen. However, to compensate for errors in the transparencies themselves or for other distortions produced by the viewer, it is sometimes advantageous to be able to adjust the transparencies so that their planes are no longer parallel.

We have introduced two additional degrees of freedom (section 5.6.3) which permit each transparency in the viewer to be rotated about axes parallel to the X-Y axes.

This gives a total of six degrees of freedom  $S_{(1-6)}$  which can be listed:-

- $S_1$  : Translation of lens (and projected image) in the X direction.  
 $S_2$  : Translation of lens (and projected image) in the Y direction.  
 $S_3$  : Translation of lens (giving image scale change) in the Z direction.  
 $S_4$  : Rotation of transparency about axis parallel to Z axis (giving rotation of image on screen).  
 $S_5$  : Rotation of transparency about axis parallel to X axis.  
 $S_6$  : Rotation of transparency about axis parallel to Y axis.

For one image, the deviation of each fiducial mark from its "reference" position can be visually estimated on the screen with the aid of a calibrated eyepiece. These deviations can be described by a set of eight numbers corresponding to the X and Y error components of each mark.

For each fiducial mark in each of the four projected images we have calculated the rate of change of X and Y components with each of the six types of adjustment.

Let us assume that a small displacement of fiducial mark  $F_1$  in one of the four images is  $\Delta X_1$ , and is due to small movements of the degrees of freedom  $S_{(1-6)}$ , then:-

$$\Delta X_1 = \frac{\partial X_1}{\partial S_1} \Delta S_1 + \frac{\partial X_1}{\partial S_2} \Delta S_2 + \frac{\partial X_1}{\partial S_3} \Delta S_3 + \frac{\partial X_1}{\partial S_4} \Delta S_4 + \frac{\partial X_1}{\partial S_5} \Delta S_5 + \frac{\partial X_1}{\partial S_6} \Delta S_6 \dots\dots 5.1$$

Each of the X and Y components can be similarly expressed, and are concisely stated in matrix form:-

$$\Delta w_i = a_{ij} \cdot \Delta S_j \dots\dots 5.2$$

$$\Delta w_i = \Delta X_i \quad (i = 1, 3, 5, 7)$$

$$\Delta w_i = \Delta Y_i \quad (i = 2, 4, 6, 8)$$

Suffixes i (1,2) refer to fiducial mark  $F_1$

" i (3,4) " " " "  $F_2$

" i (5,6) " " " "  $F_3$

" i (7,8) " " " "  $F_4$

We now assume that the total displacement of each fiducial mark is given by:-

$$e_i = \Delta w_i + v_i \dots\dots 5.3$$

where the  $v_i$  are the X and Y components which are not caused by the  $\Delta S_{(1-6)}$ , and in general cannot be completely corrected.

We wish to minimise the set of  $V_i$  according to the principle of least squares, that is, to find a set of adjustments  $P_j$  which reduce  $V_i V_i$  to a minimum.

From 5.2 and 5.3

$$v_i = e_i - a_{ij} \cdot \Delta S_j$$

and for  $v_i \cdot v_i$  (minimum):-

$$v_i \cdot \frac{\partial v_i}{\partial P_j} = 0$$

$P_j$  is made equal to  $\Delta S_j$  and thus:-

$$-a_{ij} \cdot (e_i - a_{ij} \cdot P_j) = 0$$

$$\text{from which } (a_t)_{ji} \cdot e_i - (a_t)_{ji} \cdot a_{ij} \cdot P_j = 0$$

where  $(a_t)$  is the transpose of  $a$ .

Thus we have:-

$$P_i = \{(a_t)_{ji} \cdot e_i\} \{(a_t)_{ji} \cdot a_{ij}\}^{-1} \dots\dots 5.4$$

All the partial derivatives  $a_{ij}$  have been calculated for the "Mini-Addcol" viewer, and each of the six required adjustments  $P_j$  can be rapidly determined using a computer program in which the estimated errors  $e_i$  are inserted, and which uses equation 5.4. It also predicts the "best fit" which can be achieved in a given situation.

The full potential of this procedure cannot yet be realised, since all the adjustments  $S_j$  are not easily accessible without removing the transparency holder. A new holder is being constructed to overcome this difficulty, and it is anticipated that the future production of composites, particularly from aircraft multispectral transparencies, will benefit from these techniques.

## 5.7 CONCLUSIONS

In spite of the increasing interest in purely numerical methods of interpretation, remote sensing still relies heavily on the pictorial display. This display is becoming more sophisticated with enhanced colour composites and colour thematic maps now becoming routinely available to the user.

For a small and relatively isolated country like New Zealand, we believe that an "in-house" photographic facility is necessary to make significant progress. It enables local "user" groups to have access to colour products enhanced for their application, and results in a build-up of expertise in techniques which are not available elsewhere in the country.

TABLE 5.1

Measured co-ordinates and distances from nominal positions ( $X_n$ ,  $Y_n$ ), of fiducial marks, using the co-ordinate system shown in Fig. 2. All dimensions are in mm.

| SCENE                    | FIDUCIAL<br>MARK | CO-ORDINATE | MSS BAND NUMBER |        |        |        |
|--------------------------|------------------|-------------|-----------------|--------|--------|--------|
|                          |                  |             | 4               | 5      | 6      | 7      |
| 2334-21123 (22 DEC 1975) | F2               | X           | -0.010          | 0.007  | -0.002 | -0.008 |
|                          |                  | Y           | 60.374          | 60.377 | 60.368 | 60.367 |
|                          |                  | X- $X_n$    | -0.010          | 0.007  | -0.002 | -0.008 |
|                          |                  | Y- $Y_n$    | 0.874           | 0.877  | 0.868  | 0.867  |
|                          | F3               | X           | 58.588          | 58.601 | 58.594 | 58.582 |
|                          |                  | Y           | 60.374          | 60.362 | 60.375 | 60.366 |
|                          |                  | X- $X_n$    | -0.012          | 0.001  | -0.006 | -0.018 |
|                          |                  | Y- $Y_n$    | 0.874           | 0.862  | 0.875  | 0.866  |
|                          | F4               | X           | 58.598          | 58.590 | 58.592 | 58.593 |
|                          |                  | Y           | 0.000           | 0.000  | 0.000  | 0.000  |
|                          |                  | X- $X_n$    | -0.002          | -0.010 | -0.008 | -0.007 |
|                          |                  | Y- $Y_n$    | 0.000           | 0.000  | 0.000  | 0.000  |
| 2389-21172 (15 FEB 1976) | F2               | X           | -0.044          | -0.029 | -0.018 | -0.004 |
|                          |                  | Y           | 60.004          | 59.980 | 59.979 | 59.989 |
|                          |                  | X- $X_n$    | -0.044          | -0.029 | -0.018 | -0.004 |
|                          |                  | Y- $Y_n$    | 0.504           | 0.480  | 0.479  | 0.489  |
|                          | F3               | X           | 58.537          | 58.545 | 58.554 | 58.565 |
|                          |                  | Y           | 60.027          | 60.012 | 60.002 | 59.993 |
|                          |                  | X- $X_n$    | -0.063          | -0.055 | -0.046 | -0.035 |
|                          |                  | Y- $Y_n$    | 0.527           | 0.512  | 0.502  | 0.493  |
|                          | F4               | X           | 58.576          | 58.569 | 58.567 | 58.567 |
|                          |                  | Y           | 0.000           | 0.000  | 0.000  | 0.000  |
|                          |                  | X- $X_n$    | -0.024          | -0.031 | -0.033 | -0.033 |
|                          |                  | Y- $Y_n$    | 0.000           | 0.000  | 0.000  | 0.000  |

TABLE 5.1 (Cont'd)

| SCENE                    | FIDUCIAL<br>MARK | CO-ORDINATE | MSS BAND BUMBER |        |        |        |
|--------------------------|------------------|-------------|-----------------|--------|--------|--------|
|                          |                  |             | 4               | 5      | 6      | 7      |
| 2282-21254 (31 OCT 1975) | F2               | X           | -0.060          | -0.043 | -0.059 | -0.056 |
|                          |                  | Y           | 59.973          | 59.977 | 59.972 | 59.959 |
|                          |                  | X-Xn        | -0.060          | -0.043 | -0.059 | -0.056 |
|                          |                  | Y-Yn        | 0.473           | 0.477  | 0.472  | 0.459  |
|                          | F3               | X           | 58.535          | 58.546 | 58.541 | 58.545 |
|                          |                  | Y           | 59.973          | 59.960 | 59.951 | 59.972 |
|                          |                  | X-Xn        | -0.065          | -0.054 | -0.059 | -0.055 |
|                          |                  | Y-Yn        | 0.473           | 0.460  | 0.451  | 0.472  |
|                          | F4               | X           | 58.596          | 58.594 | 58.590 | 58.601 |
|                          |                  | Y           | 0.000           | 0.000  | 0.000  | 0.000  |
|                          |                  | X-Xn        | -0.004          | -0.006 | -0.010 | 0.001  |
|                          |                  | Y-Yn        | 0.000           | 0.000  | 0.000  | 0.000  |
| 2192-21265 (2 AUG 1975)  | F2               | X           | 0.010           | 0.000  | -0.004 | -0.009 |
|                          |                  | Y           | 60.355          | 60.340 | 60.333 | 60.348 |
|                          |                  | X-Xn        | 0.010           | 0.000  | -0.004 | -0.009 |
|                          |                  | Y-Yn        | 0.855           | 0.840  | 0.833  | 0.848  |
|                          | F3               | X           | 58.587          | 58.576 | 58.575 | 58.571 |
|                          |                  | Y           | 60.352          | 60.374 | 60.369 | 60.363 |
|                          |                  | X-Xn        | -0.013          | -0.014 | -0.025 | -0.029 |
|                          |                  | Y-Yn        | 0.852           | 0.874  | 0.869  | 0.863  |
|                          | F4               | X           | 58.581          | 58.581 | 58.585 | 58.588 |
|                          |                  | Y           | 0.000           | 0.000  | 0.000  | 0.000  |
|                          |                  | X-Xn        | -0.019          | -0.019 | -0.015 | -0.012 |
|                          |                  | Y-Yn        | 0.000           | 0.000  | 0.000  | 0.000  |



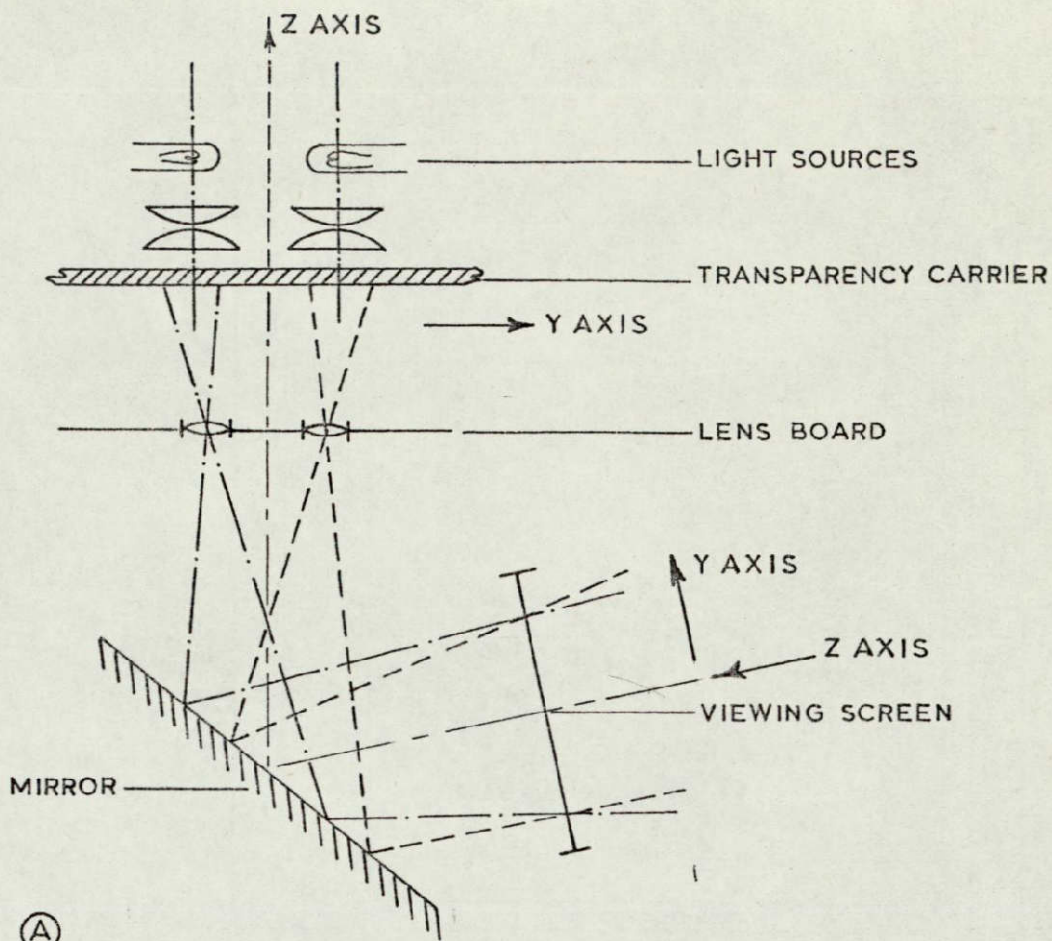


Fig. 5.1 Example of a part of LANDSAT scene E-2805-21163 Band 7 with line work of tenure information combined for field identification purposes.

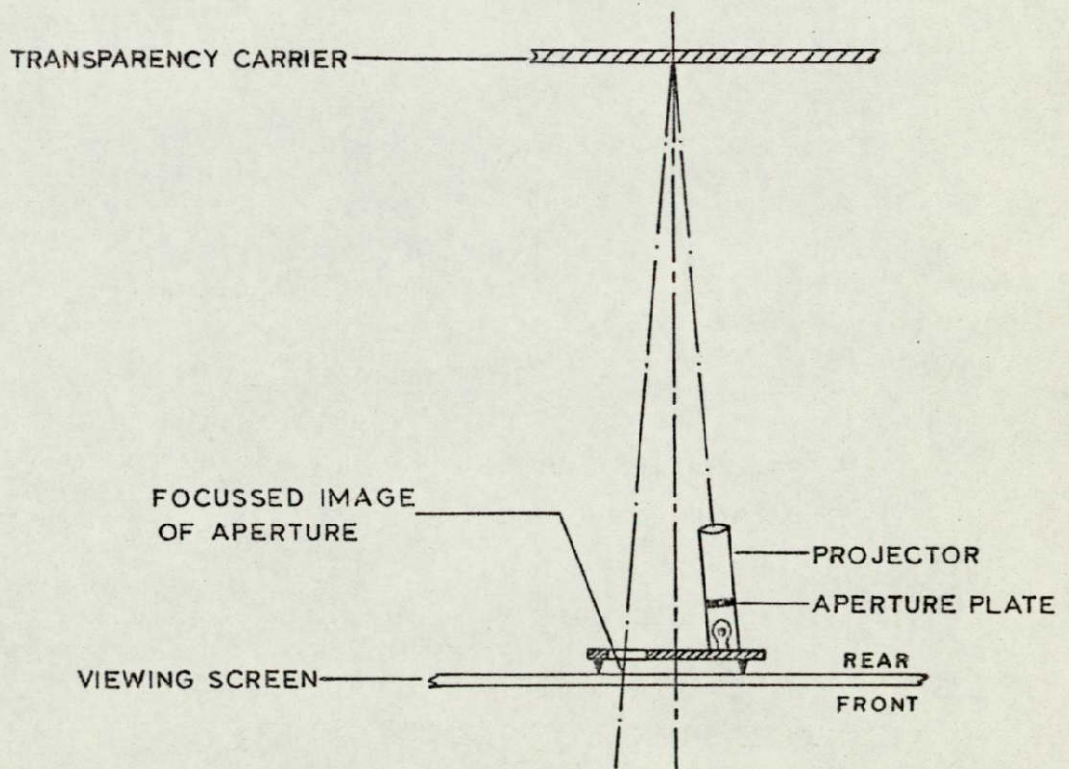
Note: Either positive or negative line information can be combined with the LANDSAT data; this figure illustrates the use of positive line data. Chapter 13 has an example of negative line information.

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(A)

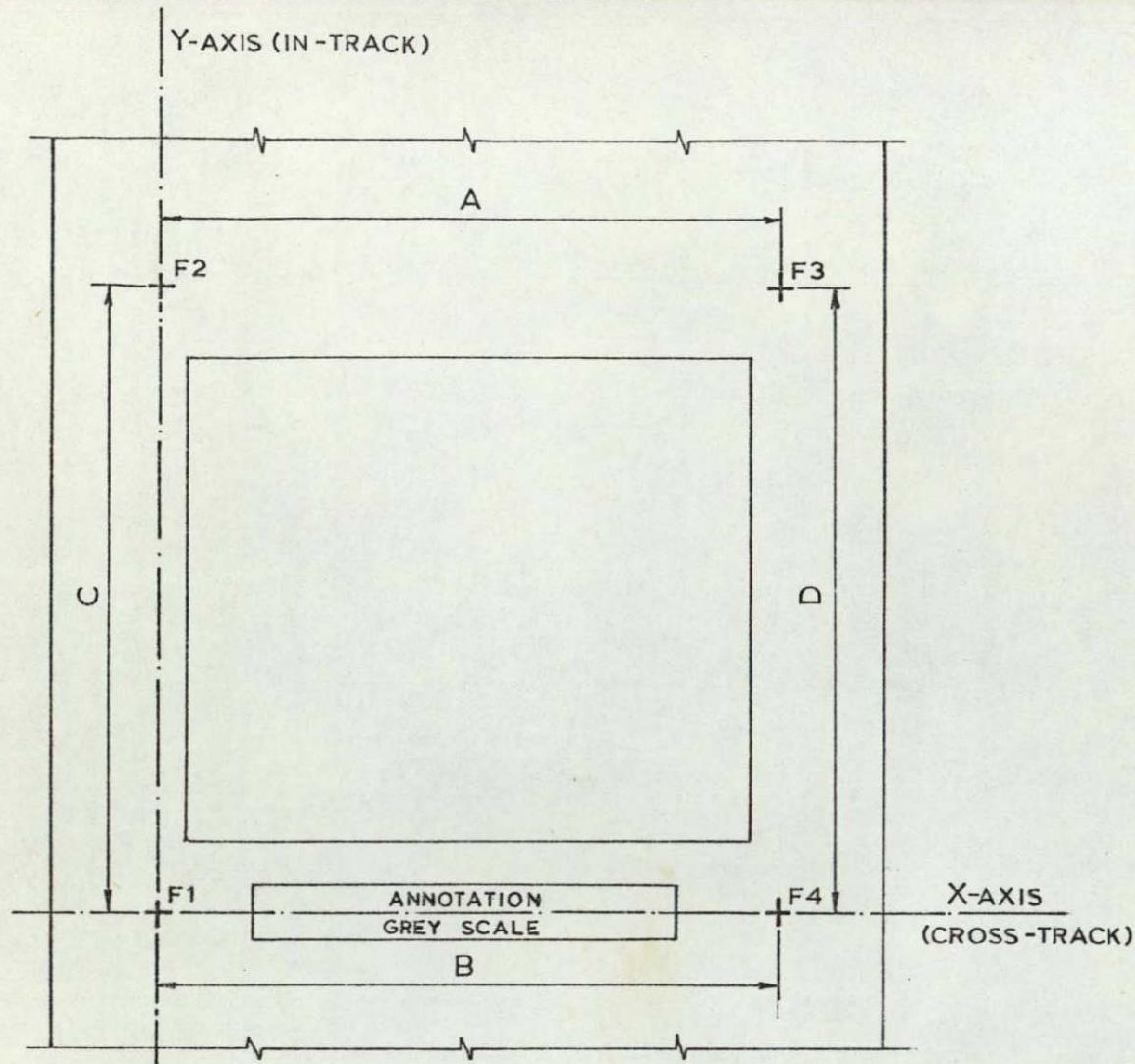


(B)

FIG.5.2 (A) COLOUR ADDITIVE VIEWER SCHEMATIC

(B) ALIGNMENT SYSTEM SCHEMATIC





NOMINAL FIDUCIAL MARK SEPARATION :-

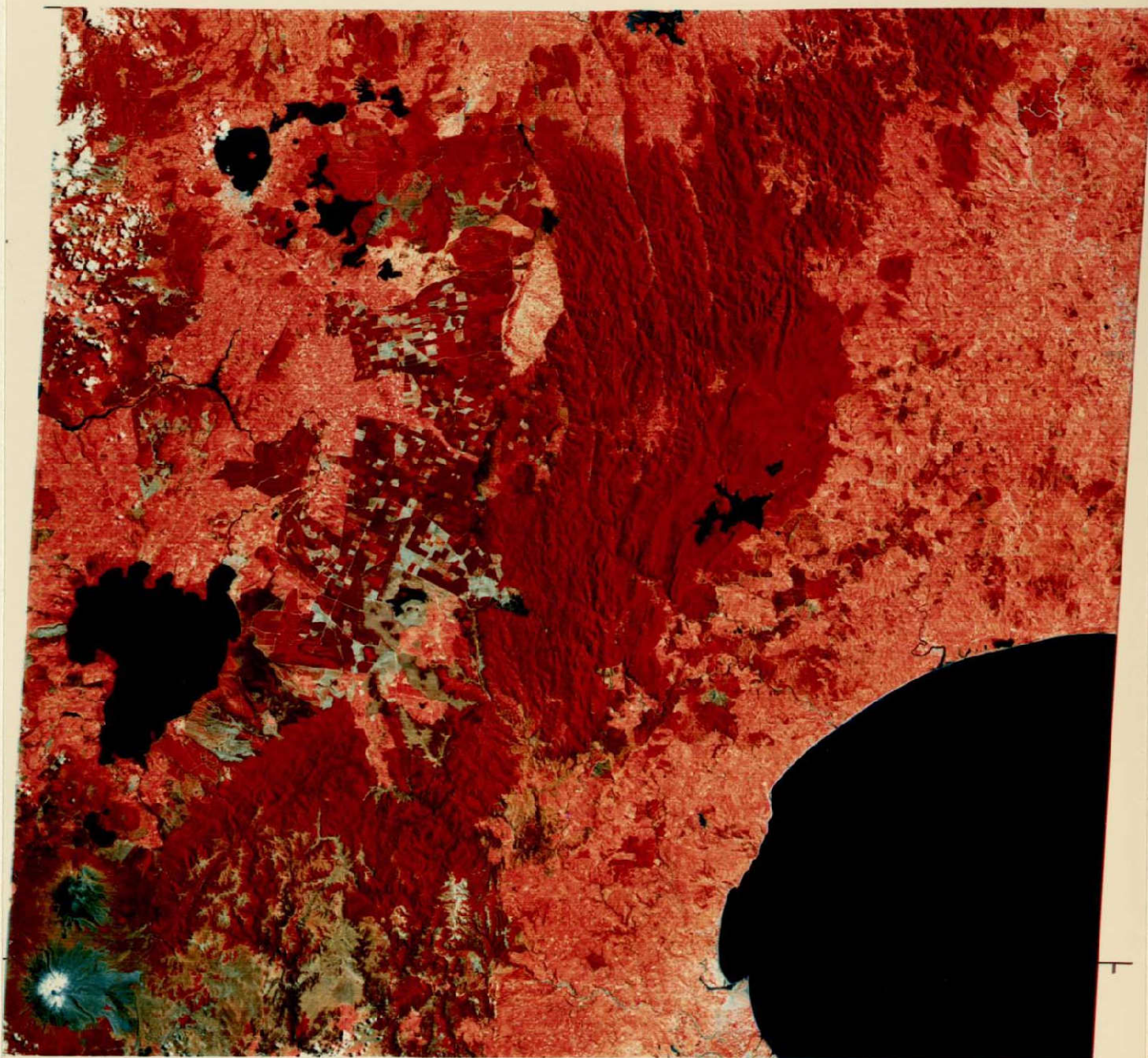
|   |   |         |   |                                             |
|---|---|---------|---|---------------------------------------------|
| A | } | 58.6 mm | } | OBTAINED FROM ERTS-1<br>DATA USERS HANDBOOK |
| B |   |         |   |                                             |
| C | } | 59.5 mm |   |                                             |
| D |   |         |   |                                             |

X-AXIS PASSES THROUGH F1 AND F4

F1 = CO-ORDINATE ORIGIN

FIG.5.3 CO-ORDINATE SYSTEM USED TO DESCRIBE  
POSITIONS OF FIDUCIAL MARKS





E176-001 S039-301 E176-301 E177-001  
 22DEC75 C S38-43/E176-46 N S38-45/E176-51 MSS 45 7 R SUN EL49 AZ001 191-4659-A-I-N-D-2L NASA ERTS E-2334-21123-3 01

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Fig. 5.4 A colour composite of LANDSAT scene E-2334-21123 produced on the "mini-Addcol" viewer using the improved registration system.

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## CHAPTER 6

LANDSAT CCT PROCESSING USING A NATIONWIDE IBM 370/168  
COMPUTER SYSTEM

I L Thomas

ABSTRACT

Physics and Engineering Laboratory employs a two stream approach to handling the LANDSAT CCT data. In this chapter the tasks performed on the nationwide IBM 370/168 system are outlined. These include: check data dumps, catalogue procedures, numerical and coded line printer output of the video data, reformatting, and supervised clustering.

6.1 INTRODUCTION

Each LANDSAT scene may be received in two forms. The first is the photographic product. Following an inspection of the photographic product, if digital analysis is felt to be applicable to a user's needs, the computer compatible tape (CCT) for that scene is requested. This contains the digital radiance values for each picture element (pixel) that makes up the scene. For some applications - particularly some qualitative overviews - the photographic product may be perfectly suitable and more than satisfactory.

Why then consider CCT products?

- (i) Each CCT product is equivalent to a first generation scene product, i.e. contrast and resolution have not been degraded by multiple copying.
- (ii) More information is packed into the CCT than appears on the photo products, e.g. each pixel can register an integral radiance level in each band from 0 to 127 (for band 7 from 0 to 63). This is of great importance for targets at low radiances or with little difference to those surrounding them. They can be much more clearly distinguished on the CCT derived product.



- (iii) For some analysis techniques such as thematic mapping or supervised/unsupervised clustering the digital information is necessary. A given target is characterised by its spectral signature (a set of four numbers for the radiance in each band) and then the scene's digital information is scanned on a pixel by pixel basis for those pixels whose set of four radiance values match the control set - within preset tolerances. In this way a scene may be typed and the area of wheat, pine forest, barley, urban areas, exposed rock, snow cover, etc. may be automatically extracted by the computer.
- (iv) The photo products often reveal sensor bank characteristics such as "striping" and contain distortions. This striping can be seen as horizontal banding and is produced by the manner the scene is scanned. Computer processing can remove such striping by reference to the calibration levels included on the tape. The distortions, too, can be removed by "geometrical correction" techniques. The former correction is important for accurate qualitative and quantitative classification of targets whilst the latter is most important for accurate cartographic work. (These processing techniques are described in detail in the following chapters (nos. 7 and 8).)

Physics and Engineering Laboratory operate a two-stream approach to computerized processing of CCT data:

- (i) a large national network machine (IBM 370/168), and
- (ii) "in-house" mini computers.

We believe this leads to wider and more efficient program development and increased ability to service varied user requirements. The larger machine is well suited to tasks involving large amounts of data manipulation and to operation by users throughout the country. These tasks include data reformatting, varied numerical and coded printouts, and batch and interactive clustering. The smaller localized machines are better suited to the development of more involved programs such as image enhancement and rectification using a small data base, before they are placed on a larger machine. This combines the ready availability and low cost of operation of "in-house" computers with short turn-around time—all advantages over the larger units.

New Zealand is a highly varied country. Within the confines of one LANDSAT scene, covering  $3.4 \times 10^4$  km<sup>2</sup>, it is not uncommon to find undeveloped rain forest, developed exotic forest, permanently snow capped mountain ranges, lakes, coastal alluvial plains, at least one river system, and a highly varied range of agricultural practices. Thus, for satisfying some investigator's needs only small areas of a LANDSAT scene will often suffice. Such small areas can usually be processed easily by the mini computers.

This "in-house" machinery too, will act as drive systems for final stage processing equipment such as the drum-write computer-to-photographic-product unit. These applications of the "in-house" computing are discussed further in chapters 7 and 8.

The New Zealand Ministry of Works and Development operate an IBM 370/168 computer system based in Wellington with terminals throughout the country. It has 3 M bytes of real storage, 16 M bytes of virtual storage, and supports 11 remote job entry terminals in addition to the ports linked directly to the machine. Peripherals include eight 200 M byte disc driver packs and six 1600 b.p.i. tape units. These facilities, combined with an 80 nanosecond basic cycle time, make it a useful system for handling the 30 M bytes commonly contained in one LANDSAT I, II scene.

The applications of CCT imagery processed on this machine to date are discussed elsewhere in this report (Chapters 10, 11, 12, 13, 17 and 19). Apart from the PEL group, staff of the Ministry of Works and Development, Water and Soil Division, and the Department of Lands and Survey, are themselves currently using the programmes described in this chapter. At this stage, the Forest Service study projects using these programs are being run by Physics and Engineering Laboratory. Our philosophy is to prepare "black box" program packages, train the user groups in their operation, maintain the CCT data base under an "alias" access system, prepare private program libraries for each user group, and then leave them to pursue their own investigations with consultative help from Physics and Engineering Laboratory when necessary. This should free Physics and Engineering Laboratory staff for development and more "non-routine" assistance tasks.

Programming Language One (PL/1) has been used for all the work currently raised on the IBM 370/168. It is a higher level language than FORTRAN but not as orthogonal as ALGOL 68. PL/1 allows great variety in the conversion routines - useful for interchanging between binary, Extended Binary Coded Decimal Interchange Code (EBCDIC), and decimal characters. In addition PL/1 very readily handles bit strings either in a bit-by-bit or byte-by-byte form. These language capabilities obviate the need for the inclusion of any machine dependent code sections in the program packages - a desirable feature if packages are to be transferable between machines. The file control too is more flexible in PL/1 than in FORTRAN and supports the variety of file management options available through the IBM 370/168 Job Control Language (JCL)

The remainder of this chapter describes the tasks which have been allocated to this large computer and discusses the likely processing developments ahead.

## 6.2 PROCESSING TASKS ON THE IBM 370/168

Five major processing areas are currently handled on the IBM 370/168:-

- (i) Receipt of the raw CCT , and disseminating copies
- (ii) Check "dumps" of the data on tape
- (iii) Reformatting the CCT data
- (iv) Preparing either numerical or coded print out products from the CCT data
- (v) Supervised clustering and thematic mapping.

Each of these is now considered in turn.

### 6.2.1 Receipt of the raw CCT from EROS and data dissemination

In chapter 2 of this report procedures are detailed that are followed after receiving the raw CCT from the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, viz. "raising" an identical copy on the IBM 370/168, cataloguing the data, and preparing copies for in-house machines. A more complete discussion is given by Thomas (1977a).

Using the "alias" access system, all data tapes are registered under the alias SGMCP9 on the IBM 370/168; where SG refers to DSIR, MCP to Dr M.C.Probine, LANDSAT 2 N.Z. Co-ordinator and "9" denoting the code as being an alias (and fixing the level of program authorization). Users may thus access the data files without passing through the Remote Sensing Section, and may retain operational programs under their own authorization without running the risk of using a program under development by another user. That is : data base is common but programs are not.

### 6.2.2. Check "dumps" of the data on tape

All the data on the CCTs is stored in "bits", which may have values of either "0" or "1". The usual radiance data is stored as an 8-bit "byte", or data word, whilst other information (e.g. MSS Data Mode/Correction Code) is stored in a bit by bit format or in a 16-bit byte (e.g. Sun calibration coefficient). All character information is stored in 8 bit EBCDIC bytes. (e.g. scene identification number).

As the fundamental mode of information storage is in "bits" a program package that would print out each record in a bit by bit format was prepared. Its main use is to check any apparent decoding anomalies right back at the input data end of the decoding procedure. This package consists of a control program which is written in the machine dependent Job Control Language. This program is charged with file location and management, in addition to calling in the PL/1 analysis procedure.



A less fundamental dump than that above is afforded by another program package. Here the bit stream is organised into 8 bit bytes and each of these 'words' is represented by an EBCDIC character in the final print out.

### 6.2.3 Reformatting the CCT data

This reformatting falls into two parts.

The original CCTs received from the EROS Data Center can be in either the 800 Bit Per Inch (BPI) or 1600 BPI 9-track format. Either format is compatible with the programs discussed here for the IBM 370/168 machine. However, to use 1600 BPI data on other 800 BPI machines a tape conversion routine must be employed.

This optional first part of the reformatting task uses a program package to split the four data files stored on one 1600 BPI tape, one for each strip of the scene, into two sets of two files with each set being stored on separate output tapes. Within the IBM 370/168 the output writing density may be selected as 800 or 1600 BPI. The user then requests an "identical tape copy" to be prepared of each of the two output tapes but in 800 BPI rather than 1600 BPI. (Each LANDSAT scene is broken into four strips aligned parallel to the spacecraft track with scan line 1 being the northernmost in the scene. Each strip contains 780 groups of 3 scan lines giving a total of 2340 scan lines aligned across the spacecraft track and proceeding parallel to it towards the south. Each of these parallel along-track strips joins contiguously with that adjacent to it in the scene and resides on the CCT product as a separate file. There are two such files to each 2400 ft 800 BPI tape.)

Not only is the LANDSAT scene split into 4 strips aligned along the orbital track, but the data is interleaved on a two-pixel by two-pixel basis. The four band MSS data is laid down for pixels "a" and "b" as follows, where the subscript indicates the MSS band number:

$a_4 \ b_4 \ a_5 \ b_5 \ a_6 \ b_6 \ a_7 \ b_7 \ c_4 \ d_4 \ c_5 \ d_5 \ c_6 \ d_6 \ c_7 \ d_7 \dots\dots\dots$

where pixels "c" and "d" follow "a" and "b" in the scan line. This combination of pixel interleaved data being broken into four parts along the scan line makes a somewhat clumsy data base for many user applications.

The purposes then of this second part of the reformatting job are to firstly provide a band by band data base that can directly feed a "drum write" system without the need for (i) unscrambling programs being run on a slower and more limited core storage mini computer, and (ii) more than one pass through a data tape. These are both time consuming operations at the very best, and

at the worst involve multiple tape and disc manipulations. The second purpose is to provide an unscrambled ordered data base for use in analysis and enhancement programs run on mini (in-house) computer systems for specialist applications. Again, this reformatting is a time and effort saving advantage even if a complete one-band scene could be accommodated in direct access memory. (One band of a complete LANDSAT 2 scene contains some  $7.6 \times 10^6$  eight bit video data bytes.)

For a more complete discussion on the characteristics of the data upon the CCT product see the report by V L Thomas (1973).

The most desirable format for such future processing as outlined above is to rearrange the four strip pixel interleaved data into four files, each containing the whole scene data for one MSS band. In addition, a fifth file of the calibration data for each line is to be placed at the start of the output tape.

Four banks of six detectors are used as the MSS sensors, leading to six lines being scanned, cross track during the one mirror sweep. These six detectors for each MSS band do vary in responsivity as do their particular filters vary in spectral transmission factor. As a result, variations in radiance response between scan lines can occur. Some allowance for such calibration differences is made in the CCT product, but to keep a record of sensor status (by reference to the solar calibration) the data is picked off the end of the scan line (the complete 56-byte block) and output as the first file on the reformatted tape.)

All five files on tape commence with a scene identification record and then the data records follow for each scan line with the scan line number impressed as the first 16 bits in each record.

In this way the calibration data can be read first off tape, stored in a mini computer, and applied to subsequent single-band whole-scene data as it is read in scan-line by scan-line.

The output tape is written at 1600 BPI so that all the data for one LANDSAT I, II scene may be held on one tape..

This reformatting is accomplished using a control program and the five subsidiary procedures. The first four of these procedures read the data from one file (one strip) of the EX-EROS CCT and split the pixel interleaved data to create four sets of four temporary data sets on disc storage. Each of these temporary data sets contains the complete one strip data for one MSS band. In addition, the last of these 'data read' procedures peels the calibration data off the end of the scan line and writes it, as the first file, to the output tape. The fifth procedure in the set reads the data from each of the tagged temporary data sets for each band, recombines the complete 185 km long scan line (3264 bytes for LANDSAT 2) and writes it to the output tape.

A complete description of the reformatting task is given by Thomas (1977b).

Typically, to reformat a LANDSAT 2 scene some 11 minutes 8 seconds of Central Processor Unit time on an IBM 370/168 is currently required. This is approximately 22  $\mu$ s of CPU time per pixel.

The above reformatting package operates in machine independent coding. To further reduce the time taken in reformatting CCTs another package is being developed and evaluated. This package uses the general registers in the IBM 370/168 16 K byte central cache storage, and bit masking techniques. Present results are most encouraging. This work is being pursued by Mr S A Crase of the Physics and Engineering Laboratory Computer Research Section on the Cumberland Computer Centre IBM 370/168 (a different machine to that reported on above).

#### 6.2.4 Numerical and Coded Lineprinter Output Products on the IBM 370/168

In addition to the program packages already discussed a further program prints out all the data in the files for the four strips on the CCT. This not only serves to locate and print out the individual pixel radiance values for a region of interest but also permits each tape's content to be routinely catalogued.

It is difficult to relate such video numerical data to ground topographic features. Consequently some form of displaying pixel band-by-band radiance values, so that they may be related to ground topographic features, was desired.

The spacecraft transmits the MSS video data as a six-bit (0-63) digitized byte at a real time transmission rate of 15.06 M bit/second. As the photomultiplier tube sensors of MSS 4,5,6 have a better signal to noise performance than the silicon photodiode sensor of MSS 7 it is possible to compress the higher light levels and expand the lower levels, thus enabling the quantization "noise" to more nearly match the detector "noise". On receipt at the ground the data for MSS 4 and 6 are decompressed using a look up table for one compression unit and MSS 5 is decompressed using a table for the other unit. MSS 7 remains in its linear mode. Thus the CCT level data usually ranges from 0 to 127 for MSS 4,5,6 and from 0-63 for MSS 7. (See Thomas (1973) and the "LANDSAT Data Users Handbook" for a further discussion).

The available data from the spacecraft can only have a maximum of 64 values spread over the decompressed 128 CCT level range. It was therefore decided to use only a 57 level separate non-overprinted character set. These 57 levels use most of the characters in the standard 60 character computer set and span the CCT level range from 0 to 127.

The control program package, known as CODEPRT, firstly splits the interleaved data into four temporary disc data sets, one for each MSS band, for the strip being considered. (The raw ex-EROS non-reformatted tapes are used in this job to reduce user expense.) The package then calls in each MSS band's temporary data set and allocates a character symbol to each pixel depending upon the radiance value for that pixel in that band. The results are then printed out on the line printer.

It has been found that some users are content to perform single band analyses using the output from one of the above MSS bands. This rather defeats the purpose of multispectral sensing and is partially overcome by guidance and the use of thematic mapping products discussed in section 6.2.5.

Further development work with these single band coded printouts must await the commissioning of the "Colorwrite" machine, discussed in detail in chapter 7 of this report. This unit will allow colour coded single band outputs to be written to photographic transparency material. The resulting geometrically rectified products can then be enlarged, etc and placed upon existent ground truth maps either individually (for fault line determinations) or superimposed (for vegetation analyses).

#### 6.2.5 Supervised Clustering and Thematic Mapping

As discussed in section 10.4.5, the human interpreter of colour composited imagery is limited to three basic colours in the imagery. Other colours are synthesized from combinations of these three. Equipment such as the I.T.C. flickering colour additive viewer described by Hempenius (1974) allow other channels of information to be added to the awareness of the interpreter. In the absence of such instruments the human interpreter can visually only accommodate three of the four MSS channels presently in operation. With the advent of the thematic mapper, scheduled for launch aboard LANDSAT-D, the number of available channels will increase to six.

The computer however is not limited to the number of colour channels capable of being monitored by the human eye. It can thus make unthinking classification decisions based on any number of multispectral channels. The human interpreter brings to the classification task in addition to colour appreciation, an awareness of texture, pattern, climate, coastal proximity, social, and economic influences, etc. The human programmer can add some of these factors to the computerized classification procedure but the best approach does appear to be a combination of a human interpreter viewing three (positive or negative) colour composited photographic channels aided by a computer prepared thematic map.

Such a thematic map is based on some form of clustering technique. The supervised clustering technique relies less on ostensibly well-defined natural groupings of spectral signatures than the unsupervised techniques. As such, it allows more

control to be applied to the classification problem by the human operation. Currently we believe that this is advisable with New Zealand data due to the small fields and high variety of farming practices encountered. As work proceeds on defining representative spectral signatures for given targets, then the application of unsupervised techniques may demonstrate greater reliability than currently exists.

At this time a spectral signature is taken to consist of the set of four band radiance levels (upper and lower boundaries in each band) that contain the majority of the radiance values for a known target. Imagining this in four dimensional space leads to the concept of a spectral parallelepiped. Hence, the clustering employed here is basically 'parallelepiped supervised clustering'. This is the form of supervised clustering employed in the time sequential thematic map discussed later in this chapter (Fig. 6.2) and in chapters 17 and 19.

In chapter 10, a revised form of this basic parallelepiped clustering is used. As outlined there an attempt has been made to include a factor that reflects the shape of the spectral reflectance curve for the target being studied. This is still under development at this stage, but the initial results are encouraging and have been used in the analysis reported in chapter 10 - that has been performed on the IBM 370/168. As MSS 4 monitors mainly the green pigments, MSS 5 monitors chlorophyll absorption, MSS 6 monitors leaf maturity/deterioration, and MSS 7 monitors the leaf 'density' a function, as given below, is incorporated for agricultural targets.

$$\text{Ratio} = \frac{\text{MSS } 5}{\text{MSS } 4} * \frac{\text{MSS } 6}{\text{MSS } 4} * \frac{\text{MSS } 7}{\text{MSS } 4}$$

The various ratio values are taken to be the mean values for the range in spectral radiance for each band for the target plus or minus the scaling accuracy of the CCT levels. This latter figure is taken to be one CCT level. Consequently upper and lower bounds to the ratio, or spectral shape factor, can be incorporated as a fifth dimension to the "parallelepiped supervised clustering".

At this stage, because of the currently encountered wide variety in spectral signatures, no maximum likelihood etc analysis has been included.

The program package, known as THEMAPP, effects this thematic mapping. Within this package one procedure prepares four temporary disc data sets, one for each MSS band, from the raw ex-EROS CCT for subsequent use. Again the non-reformatted data is used in the interests of computing economy.

The second procedure in the package screens each pixel's radiance values against the allowable four MSS band gates. If the index IRAT = 0, the spectral shape factor option is disabled;

but if IRAT is set to some integer other than zero, the option is invoked. (IRAT is input with the data to the second procedure and acts as a numerical switch between the two options. The value of IRAT, if not 0, controls the tolerance on the shape factor - see later.)

The standard procedure, with IRAT = 0, admits pixels whose radiance values have satisfied the four band limits to the target set, and prints out a representative symbol in that pixel's topographic location. The number of pixels falling within such a four dimensional parallelepiped is tallied and an area assigned to the coverage in the test area by the target being considered. This area is based on the nominal area sensed by each pixel from nominal satellite altitude (i.e.  $56 * 79$  m from 920 km). Following this area assessment, the occurrence frequency in each band, for each target, is studied and the mean and standard deviation derived. Based on these figures, revised spectral signatures are suggested by the computer as being the mean plus or minus one standard deviation, rounded up or down to the nearest CCT level. This is based on the assumption that generally some 65% of the target pixels could be expected to lie between plus or minus one standard deviation from the mean. The previous occurrence plots were expressed in CCT levels. A further plot is produced with the occurrence frequency expressed in radiance terms (mw ster-1 cm-2 integrated over the bandwidth) using the LANDSAT 2 calibration data effective after 15 July 1975 (GMT).

If IRAT is set equal to some integer other than zero, the spectral shape factor option is included as a fifth dimension in the classification parallelepiped. As this option is only invoked following the determination of spectral signatures based on the mean and standard deviation for each target determined from the training targets, the ratio takes the mean for each band and allows a tolerance of  $\pm$ IRAT CCT levels about that mean. (Commonly IRAT is set equal to one representing the scaling tolerance in the CCT data.) This is then passed to the classification section and acts as the fifth gate.

How then is one of the five dimension parallelepiped clustered thematic maps prepared?

In Fig. 6.1, a flow chart is presented outlining the various steps in the production of such a thematic map. Basic to such production is the routine:

- (i) use the 57 level coded print out to determine the bounds to the spectral signature gates for each of the four MSS bands for each target
- (ii) run the thematic mapping program, without the spectral shape factor included, to determine the mean and standard deviation of the frequency of occurrence distribution of pixels falling within the spectral signature limit bounds for each MSS channel

- (iii) based on the revised suggested spectral signatures select the spectral signature ranges that best typify the training target
- (iv) insert the revised signatures into the thematic mapping program and run it, with the spectral slope factor included, over the larger evaluation area.

The results of the application of this package to an agricultural target are presented in chapter 10.

Whilst this analysis package was being developed, an application of four dimensional supervised clustering arose.

The Eyrewell State Forest (around 43.42°S, 172.33°E) was subjected to violent wind damage in early August 1975. As it happened, the LANDSAT 2 pass of 2 August 1975 recorded data over the area on the day following the major damage. It was decided to run the supervised clustering package on the scenes covering this area taken on 2 August 1975 (2192-21265) and 31 October 1975 (2282-21254). For each scene the clustering revealed trees that exhibited "healthy" spectral signatures. Those trees windthrown immediately prior to the 2 August scene have still appeared in it as "healthy" but by the 31 October scene the signatures have changed significantly. By colour compositing these two line printer outputs an assessment of the extent of the damage has been formed. Obviously by automatically counting pixel numbers in each output, a quantitative estimate of the area of damage at that time may be deduced.

The results of this two colour superposition are presented in Fig. 6.2. Pixels that could contain damaged trees appear as red whilst those that apparently have retained their health appear as yellow or green. Ground checking, such as reported in chapter 19, has established that in this case variation in permitted spectral signatures has led to the clustering program including young trees and selectively thinned tree stands with those trees thought to be damaged. However this is a problem related to the spectral signature determination not to the computing technique.

On compositing the above two line printer outputs considerable difficulties were encountered in achieving correct feature superposition. This was mainly due to variations in spacecraft attitude and altitude between the two scenes. The advent of geometric rectification software in our library such as is discussed in chapter 8 will reduce, if not obviate, these difficulties.

Future work in this thematic mapping field falls into two categories. Currently the main work has been done in the batch mode of computer operation. By using more of the available storage in the IBM 370/168 it is hoped to allow interactive supervised clustering to be performed on preselected sub-images

of a LANDSAT scene. This should greatly increase the analytical power of the package. The other major study must be directed at ways of determining more representative spectral signatures and methods of implementing their discrimination in the computer. The former will probably be aided by a judicious choice of the time of year for recorded imagery to highlight the target of interest. The latter will probably implement more of the maximum likelihood classification concepts.

#### Acknowledgements

The assistance of Mr S A Crase of the Computing Research Section has been of great benefit to all phases of marrying computer concepts and LANDSAT data.

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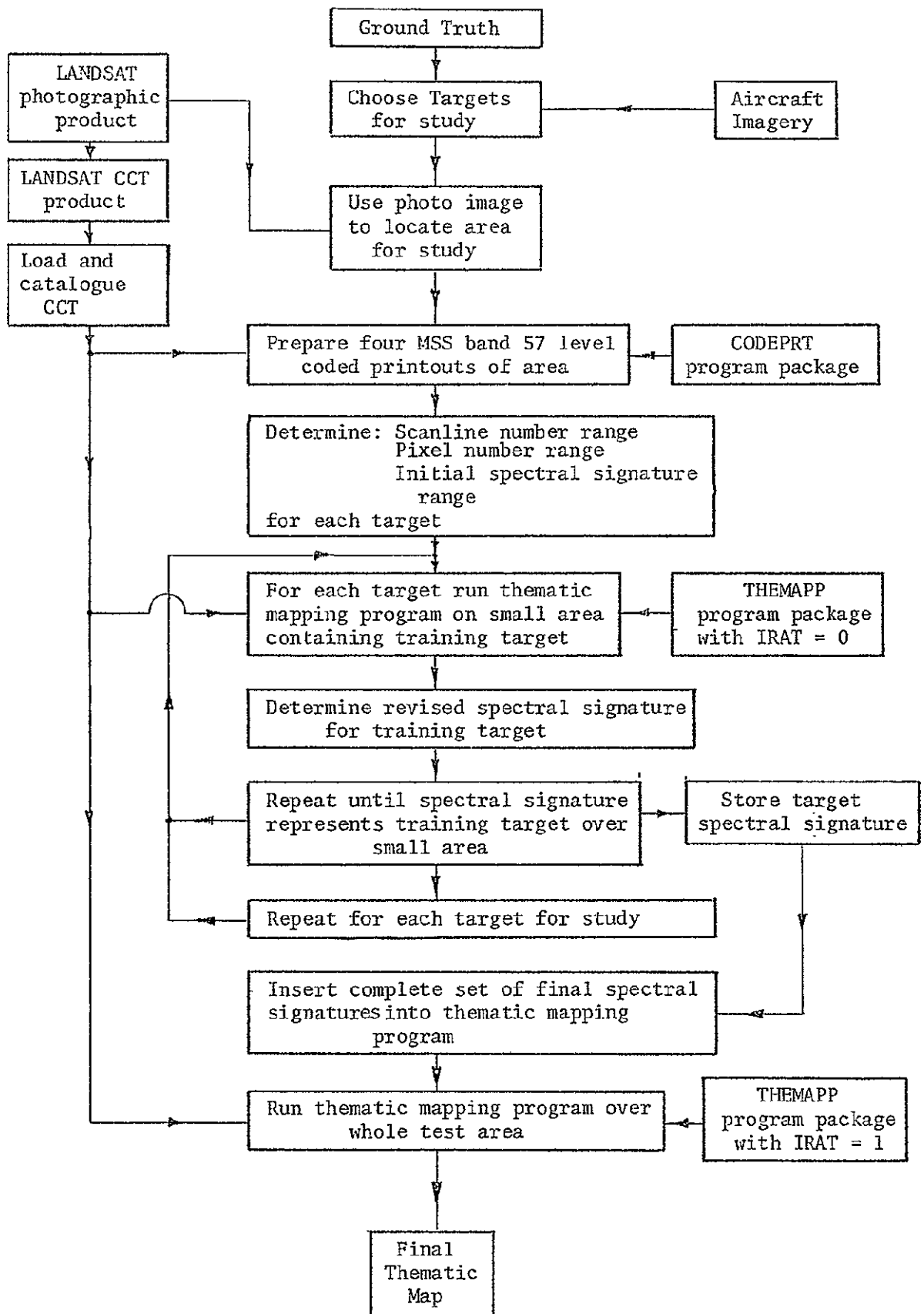


Fig. 6.1 Flow chart for 5 dimensional parallelepiped supervised clustered thematic mapping

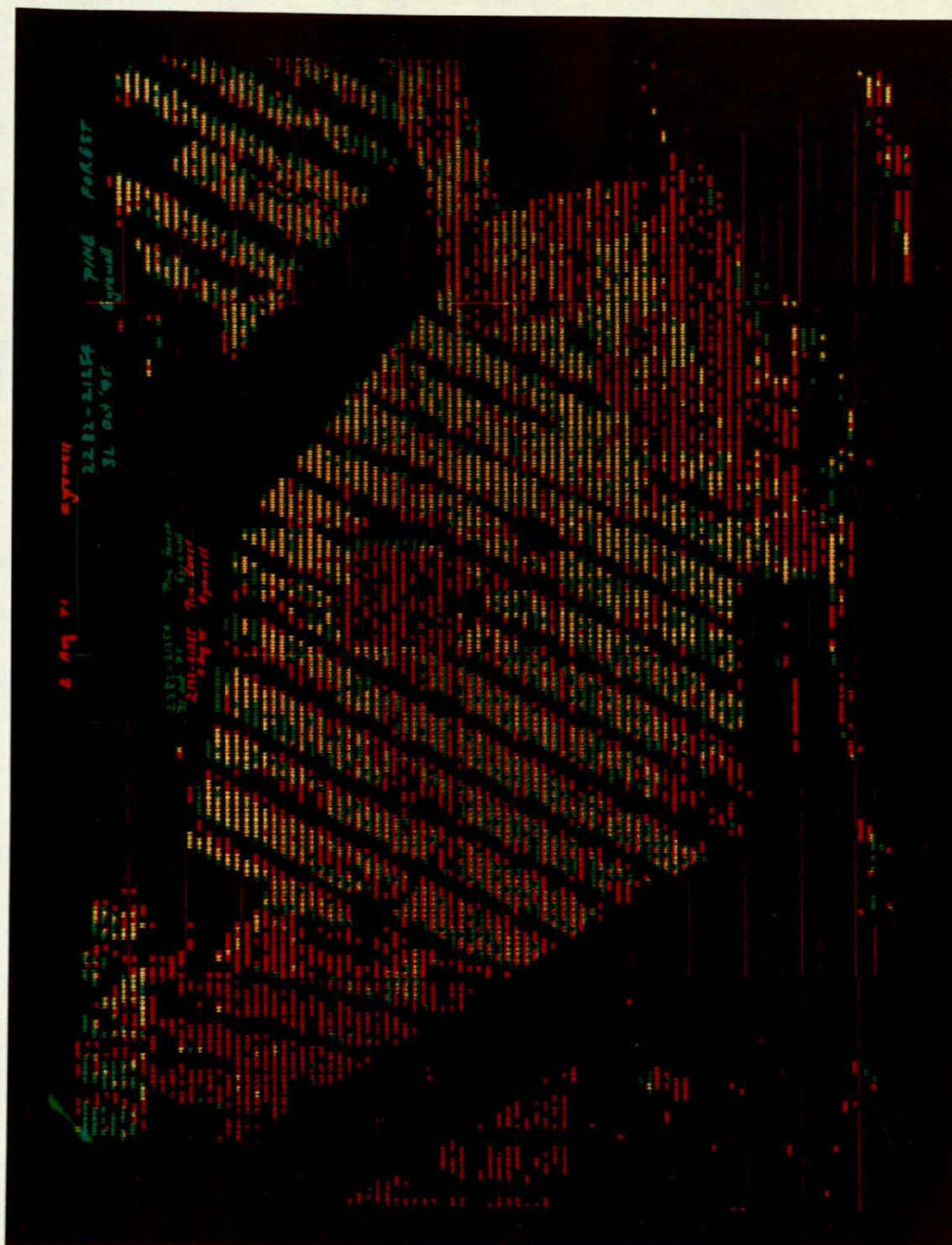


Fig. 6.2 A colour coded comparison of the extent of damage to the Eyrewell Forest. Supervised clustering applied to "healthy" trees for the 2 August 1975 (2192-21265) scene shows red and for the 31 October 1975 (2282-21254) scene shows either yellow or green. The difference between the two areas is indicative of the extent of the damaged area.

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